HYDRO HYDROGEN PILOT PROJECT
FOR NIYAZOBA, KUBA-KHACHMAS, AZERBAIJAN

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Summary

This report describes the technical options for the Hydro-Hydrogen Pilot Plant planned for the hydropower plant in Niyazoba village, Kuba-Khachmas region, Azerbaijan Republic. A provisional technical project outline with associated costs is summarized.

The Niyazoba hydropower plant will produce electricity due to the difficulties of matching energy generation with local electricity demand. The system will store an excess of energy to generate hydrogen for later use. It will provide a technical demonstration of the compatibility of hydrogen technologies with renewable energy generation, and act as a model for further cogeneration plants to be built at hydropower plants in rural Azerbaijan. 500 kW will be made available for hydrogen generation in Niyazoba.

The engineering options and associated costs reported are based on the information supplied by a range of manufacturers, including Siemens, Norsk Hydro, Stuart Energy, Air Products etc. Electrolyser technology at the 500 kW scale can be sourced from more than one supplier, and some suppliers have significant experience in the field.

A hydrogen generating electrolyser with on-site hydrogen compression and storage facility is estimated to cost about $1,000,000 (excluding land costs). A further $128,299 will be required for hydrogen gas management (including personnel, hydrogen transit storage and delivery) and $355,000 will be required for oxygen gas management (including on-site compression and storage, transit storage and delivery). An economic analysis of hydrogen production costs indicates that in comparison with hydrogen produced in the USA, hydrogen generation in Kuba-Kahchmas region will be much cheaper, particularly if the electricity is supplied at zero cost to the electrolyzer plant. In this case, hydrogen production costs will be approximately $3.1 per kg. Potential local end-users of hydrogen and oxygen produced will be identified.

I. BACKGROUND

Energy supply is essential in the development of Azerbaijan. However, most of the rural population remain reliant on wood and diesel fuel to heat their homes and to cook that lead to deforestation in many regions of the republic, while increasing the amount of greenhouse emissions. In order to promote regions' development, Azerbaijan must seek new ways of generating energy which do not pass excessive cost on to the consumer, which do not sacrifice the natural environment, and which protect the health of the population. Several policies have been outlined by the Azerbaijan Government to develop such strategies. Azerbaijan has great potentialities for using non-traditional energy resources due to its geographical situation, climate and economical infrastructure. Solar energy can be used in Azerbaijan in rural regions for heating and electricity supply purposes as well as in some fields of industry and agriculture. Calculations have shown that with the help of solar collectors using little potential of solar energy of a total area of 10,000 m^2, 13 thousand tons of conditional fuel can be saved and 23 thousand tons of CO_2 can be reduced annually. There are favorable conditions for the use of wind energy in Azerbaijan. Potential of wind energy resources allows to reach 800 MWt. It is possible to produce annually 4 billion kWt electrical energy. It allows to economize 1 billion kWt/h conditional fuel, while reducing 3.7 million tons of CO_2 annually. A number of measures have been adopted in Azerbaijan to use alternative energy resources. Development of small hydropower plants (SHPs) is one of them. These measures are based on various factors, including the abundance of hydropower potential of the republic. Evaluations have shown that Azerbaijan's hydropower potential amounts to 4.9 billion kWt/h, and the economic effect gained from small hydro power plants amounts to 1.7 billion kWt/h. Utilization of this potential will allow saving annually 500 thousand tons of conditional fuels. It means reducing 1.5 million tons of CO_2 annually. Hydropower is not only environmental-friendly, but also cost effective. Hydropower plants have the highest operating efficiency of all known generation systems. They are largely automated, and their operating costs are relatively low. Hydropower plants also play an important role in water resource planning, in preventing flooding, making rivers navigable, solving irrigation problems and creating recreation areas.

The proposed hydrogen generation station will be situated at the Niyazoba hydropower station in the Kuba-Khachmas region of Azerbaijan Republic. The project aims to demonstrate the potential of using hydrogen to store the energy generated by intermittent renewable sources such as hydropower, in Azerbaijan. The Azerbaijan government has expressed interest in the prospects for hydrogen energy as an enabling technology for increasing the efficiency of SHP (see Annex IV) in individual regions, and has taken a particular interest in the Kuba-Khachmas project. A long term goal of this project is to achieve a successful model of hydropower and hydrogen technologies, to further implement in other regions and to provide large employment opportunities in rural Azerbaijan.

An outline of the requirements of this Engineering Report is given in Annex I. Description of the works related to SHP stage with associated costs is presented in Annex II. Further background information on the context of this proposal regarding energy in Azerbaijan, and the basic technical principles involved in the proposed plant, can be found in Annex IV.

NIYAZOBA PROJECT SITE DESCRIPTION

A. Introduction

Two hydropower stations each 1 MW are planned in Niyazoba village in the Kuba-Khachmas region of Azerbaijan Republic. This site will be made available for the purposes of a renewable energy-hydrogen demonstration project designed on the basis of cooperation of International

Centre for Hydrogen Energy Technologies (ICHET), United Nations International Development Organization (UNIDO) and International Ecoenergy Academy (IEA).

B. Location

The Niyazoba Hydropower Project will be located in Niyazoba village, Khachmas district of Kuba-Khachmas region, Azerbaijan Republic. Kuba-Khachmas region is situated in the North border of the republic. The plant site lies on the River Gudialchay. The Gudialchay River is not open to navigation or to water transportation, so the plant will be used only for electricity generation.

C. Topography and Seismology

The Niyazoba Hydropower Plant will be located in Niyazoba village in a river valley with specific wonderful landscape. Niyazoba village is situated in the lower reaches of Gudialchay, in the transit part of the river. The plant area is open and wide at the foot of the Great Caucasus Mountains. There is no recent record of significant seismic activity in the area.

D. Climate

The dam site is located on the lower reach of the Gudialchay River in Kuba-Khachmas region. The average temperature in this region is 10.2-12.5ºC, average relative humidity - 78%, average rainfall – 306.8 mm, and average air (wind) speed – 2.3 m/s. Most of the precipitation is observed from March to June and also from October to December. Annual solar radiation is below 124 $kkal/sm^2$. The number of annual sunny hours is less than 2,000 and the number of annual windy days (with higher than 15 m/s speed of wind) is 10. According to the data of two hydro-meteorological stations during the last ten years temperature anomaly in Guba-Khachmas region was changed within the interval of -1.16°C + 1.72°C. The greatest value of temperature increase (+ 1.37°C) was observed in 2000. During that period the anomaly in precipitations in Guba-Khachmas region was 2.6%.

E. Hydropower Station

The Niyazoba Hydropower station will be a middle head with 2,000 kW/h total capacity. The width of the river at plant site is about 10 meters. The plant is expected to generate 43.70 kW/h daily and 15,950.0 kW/h annually with 8,000 usage hours. The investment is $1,800 per first station (including dam and auxiliary infrastructure) and $1,400 (excluding auxiliary infrastructure). Hydropower stations will be constructed over a period of 12 months. The Niyazoba power plant will have a dam. There will be no additional inundation area after the completion of the Plant, since it will be constructed on the hillside of Niyazoba village. Up to 25% of the electricity generating capacity of the Niyazoba hydropower plant (up to 500 kWt) will be made available to generate hydrogen for this project.

F. Population Centers

Niyazoba village is located in Kuba-Khachmas region, Khachmas district of Azerbaijan Republic. The center of Niyazoba village is 5 km from the recommended dam site. The project site is 15 km away from the Khachmas district. The Niyazoba village has a population of 6,000 (end of 2004).

G. Transport to Site and other Amenities

The dam site of the Niyazoba Plant is about 5 km away from Niyazoba village and 15 km away from Khachmas district. An existing highway will provide convenient access to the dam and powerhouse sites, and facilitate any transportation requirements. Access roads will be widened and refitted to meet the construction needs for the plant. The construction water will be taken directly from the Gudialchay River and the domestic water from the wells to be sunk. The electricity for construction will be provided by the 35 kW Niyazoba substation after erection of

10 kV transmission lines and a mains transformer, which will connect the powerhouse to the substation. A 75 kW diesel generator may be provided as backup power.

II. PROPOSED HYDROGEN GENERATION STATION

A. Introduction

According to a report published by the United States National Renewable Energy Laboratories (NREL) in March 2004, there are few hydrogen generators currently available commercially to match the capacity of this plant (Ivy, 2004). The main manufacturers selling eletrolysers of the scale required are the Norsk Hydro, Teledyne and Stuart Energy companies. Norsk Hydro has extensive international experience with plants of this scale based on renewable energy sources. The Norsk Hydro electrolyser has the highest energy efficiency including compression. The energy requirement given in the table below is the energy required for hydrogen production by each manufacturer. All numbers include compression. The energy efficiency of the process is given in the table. The pressure is ranging from 4 to 30 bar. The reported efficiency is only for the electrolyser and does not include electricity production efficiency.

Table: Energy efficiency (Ivy, 2004)

Manufacturer	Energy requirements (kWh/kg)	Production	System efficiency (%)	Pressure (bar)
Stuart	53.4	5.4	73	24
Teledyne	62.3	3.77	63	4-8
Norsk Hydro	53.5	43.59	73	30

Since the numbers in the Table include compression to operation pressure the Norsk Hydro electrolyser represents the best energy efficiency. It has the same system efficiency but operates at a pressure 6 bars higher than the electrolyser produced by Stuart. This could be due to the fact that the production rate is almost tenfold. Since Norsk Hydro was the only company able to provide up-to-date technical and cost data for their units on request, the following description of a hydrogen generating station at Niyazoba is based around their model and engineering system. It is expected that these costs and proposed plant layouts will not vary significantly between Norsk and the only other competitor able to supply systems in this size range (Stuart Energy and associated companies). The other leading electrolyser manufacturers were contacted, but they were not able to provide sufficient technical data on which to estimate technical feasibility, demonstrate prior experience, indicate costs, or provide delivery to Azerbaijan. The size of the proposed electrolyser plant will be approximately 500 kW.

B. Hydrogen Generation and Storage

Hydrogen Generation by Electrolysis

Electrolysis of water is the electrochemical process during which numerous chemical reactions take place in the presence of an electric current. Water dissociates to oxygen and hydrogen when electric current passes through and electrolyte is present. Positive charged ions are driven to the negatively charged cathode, where hydrogen molecules are produced. Respectively, oxygen is produced at the positively charged anode [NREL,1995]. The three major technologies, currently under consideration for electrolytic hydrogen production, are classified as alkaline, polymer membrane and ceramic oxide electrolyte [Momirlan and Veziroglu, 1999, Momirlan and Veziroglu, 2002]. They produce high purity H_2, of high efficiency that rises up to 70% approximately. The modern electrolysis cells consume 5-6 kWh for each Nm^3 produced [Mc. Lellal et al., 2004, NREL, 1995]. Because this method requires significant power, it is not economically feasible for all applications. With the high delivered cost of electric power, this process has been economically non-competitive with other methods of hydrogen manufacture based on fossil fuels along with thermal energy input. However, electrolysis has been used for long wherever electric power is available cheap or pure hydrogen was needed in special applications like hydrogenation of oils or where there is a renewable energy source available such as hydro, solar or wind power.

Electrolysis hydrogen generators produce hydrogen and oxygen following the chemical equation:

$$2\ H_2O + Energy \rightarrow 2\ H_2 + O_2$$

This chemical transformation occurs in an electrolytic cell. If the cell is exposed to any flow of electric current it starts the process of electrochemical separation of water molecules into its two components - oxygen and hydrogen. The gases are emitted from the electrodes and are separated and captured in the electrolytic cell.

The Norsk Hydro electrolyser is a bipolar alkaline design. Electrolysis cells are connected in series, and hydrogen is produced on one side of the cell, oxygen on the other. A membrane is placed between the cathode and anode, which separate the hydrogen and oxygen as the gases are produced, but allows the transfer of ions. In an alkaline system, the reactions at each electrode are:

Alkaline Hydrogen Production at the Cathode

$$2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$$

Alkaline Oxygen Production at the anode

$$2\ OH^- \rightarrow \tfrac{1}{2}\ O_2 + 2\ H_2O + 2\ e^-$$

The operating characteristics of the Norsk Hydro electrolyser are summarized in their quotation for this project in Annex IV. The plant will generate an estimated 82 normalised cubic meters of hydrogen gas per hour ($Nm^3\ hr^{-1}$ or 7.4 kg hr^{-1}), 1968 $Nm^3\ day^{-1}$(176.9 kg d^{-1}), and 718,320 $Nm^3\ yr^{-1}$(64,578 kg yr^{-1}).

The plant can be stopped and started at any time, is automatic and the production can be regulated down to 20%. The electrolyser can therefore operate at between 20-100% of capacity, allowing for variations in the quantity of electricity available to generate hydrogen. The regulating range of the electrolysers (20 to 100%) does not affect the gas quality. The offered electrolyser capacity can easily be increased to between 100-150 $Nm^3\ hr^{-1}$ by extending the foundation and adding more cells. The high pressure compressor has a maximum capacity that matches this increase by installing a larger motor and increasing the speed.

The life time of Norsk equipment is estimated at more than 50 years. Intervals between refurbishing the cells are around 7-10 years; this is not mandatory but keeps the energy consumption low. Refurbished cells are delivered with a new guarantee and when they arrive on site Norsk change the cell package in less than two days. The customer is then given credit for the used cell package, dependent on the condition.

Primary Storage

Many different hydrogen storage schemes have been investigated and applied in research programs and demonstration since the first "oil shock" in 1973. Some of the options are listed below:

- compressed hydrogen gas (CHG) in cylinders or tanks

- tethered balloon, “bag”, or water displacement tank (low pressure CHG)
- hydrogen adsorbed into metal to form metal hydride (MH)
- liquid hydrogen (LH2) in cryogenic tanks
- adsorption on high-surface-area carbon powder in tanks
- encapsulation in glass micro-spheres (experimental)
- adsorption on carbon “nano-tubes” (experimental)
- in water (H_2O) (not a “fuel”)
- in ammonia (NH_3)
- in liquid hydro-carbons: gasoline, diesel fuel, alcohol, liquid natural gas (LNG), propane or butane (LPG), etc.
- in gaseous hydrocarbons: compressed natural gas (CNG), bio-gas, etc.

The first three hydrogen storage options above, CHG, MH, and LH2, are the “state of-the-art” methods most frequently applied in vehicular and stationary applications. Hydrogen can be compressed into high-pressure tanks. This process requires energy to accomplish and the space that the compressed gas occupies is usually quite large resulting in a lower energy density when compared to a traditional gasoline tank. Compressing hydrogen is similar to compressing natural gas, though as hydrogen is less dense the compressors need better seals.

Storage of hydrogen at the Kuba-Khachmas site will be provided by a large storage tank with a storage capacity of 5 m^3 (200 bar g). This storage facility represents an intermediate storage step before bottling, piping or truck transport to the site of use. The tank will store up to the equivalent of 10 hours of generated hydrogen and act as a means of temporarily balancing supply and demand. Additional storage may be added to increase the storage capacity to 24 hours of production. Such additional storage would add $67,000 to the price quoted by Norsk Hydro.

Hydrogen Dispensing System

There are a number of dispensing options. The choice of system is dependent on the downstream use of the hydrogen generated.

- Valves can be added to the Norsk storage system to enable a dispensing function and subsequent delivery of hydrogen by road for off-site hydrogen consumption. This may represent the lowest cost option, as the only addition to the plant is a few valves supplied by Norsk, and purchase of hydrogen delivery containers which can be recycled.
- A specialized dispensing system may be purchased from Air Products to enable delivery of hydrogen by road for off-site hydrogen consumption, probably in Kuba and Khachmas.
- A refueling station for vehicles may be designed for the site to supply fuel cell vehicles with fuel.
- A pipeline may deliver hydrogen for on-site consumption, e.g. to a fuel cell.
- A pipeline may supply hydrogen Kuba and Khachmas districts. This option is fraught with problems and may prove costly in the short-term, with only longer term economic benefit.

Secondary Storage/Delivery

Hydrogen generated by the electrolyser and stored in the temporary storage tank may be dispensed to discrete tanks for delivery by road, to the site of sale or use.

Bulk Hydrogen Containers

Bulk hydrogen containers on trucks may be used for delivery to the point of use. Local knowledge is required to understand what technology is available in Kuba-Khachmas region for this purpose.

Discrete Hydrogen Containers

The most attractive technical option for hydrogen storage in discrete containers is the Quantum system of high pressure vessels. It may also be the most attractive economic option since the containers are low cost and contain large quantities of highly compressed hydrogen, compressed by a dedicated compressor. The Quantum TriShield™ all-composite compressed gaseous hydrogen and natural gas storage cylinders are rugged, low cost, ultra-lightweight, storage efficient (high volume) storage tank to improve the range and safety of hydrogen powered technology. The tank is designed to meet all applicable regulatory standards and OEM- specific validation tests, and holds pressures up to 10,000 psi (700 bar). This storage system offers outstanding safety margins and reliability that also provides significant weight and price advantages.

The advanced composite tank technology incorporates a unique "TriShield" design. Some of the unique features are:

- Proprietary modified polymer liner, optimized for improved low-temperature flexibility
- Permeation resistant liner technology
- One-boss opening design to minimize leak-paths
- Optimized H_2 seal system to maximize reliability
- High safety margin: design pressure safety rating exceeding industry requirements
- Premium carbon fiber inner layer protects against corrosive agents normally present in automotive service
- Proprietary high impact resistant outer shell

Alternative options are the more regular storage tank options made of aluminium or carbon fibre, offered by Air Products amongst other competitors. Hydrogen is normally compressed to between 200 and 250 bar for storage in cylindrical tanks of up to 50 litres. These tanks may be made from aluminium or carbon/graphite compounds and can be used for either small industrial projects or transportation. These tanks are produced by Luxfer, UK and can be purchased for $550 per 50 litre cylinder.

<u>Customised Hydrogen Dispensing/Refueling Stations for Fuels Cells</u>

Specialised hydrogen dispensing systems may be required for safe delivery of hydrogen to the point of use. This may be necessary for the supply of hydrogen to a fuel cell on the plant site or to fuel cell vehicles operating from the site. The hydrogen generated by the Norsk Hydro electrolyser would need to pass through a dryer and deoxidizer to remove oxygen and water residues.

Air Products *Packaged Fuelling Stations* are designed for minimal installation and can be used with on-site generation. The stations are designed for high efficiency by taking advantage of the available pressure from the hydrogen supply source. The dispenser is integrated into the delivery equipment package and stations will service fleets from as small as 2 light-duty vehicles to up to 6 buses. *Customised Fuelling Stations* for specific requirements that demand customization. Air Products is able to offer the low cost option through their experience in fuelling stations and industrial hydrogen where they own equipment. They also provide an extensive range of engineering services including fuel monitoring, maintenance facilities, operation and safety training. Individual Fuelling Station components are also available. The dispenser is the critical interface for vehicle fuelling and Air Products' technology allows communication between the receptacle and the fuelling station. The customer interface is automated and easy to use. Options are available for multiple fuelling pressure, blended fuels and product metering.

Quantum also offers a service for customised hydrogen dispensing systems. In the area of Refueling Infrastructure, Quantum offers several hydrogen refueling systems focused on early infrastructure development, targeting fleets of one to twenty vehicles. Quantum's ultra-light weight composite fuel storage, fuel injection and metering technologies, electronic control products and systems integration capabilities have enabled the company to develop a product portfolio with state-of-the-art technologies and products, a diverse customer base, and alliances with partners such as General Motors and Sumitomo corporation. Quantum is a Tier 1 OEM supplier and a member of the GM Fuel Cell Alliance of fuel cell commercialization companies. Quantum's customer base also includes Toyota, Opel, Hyundai, Suzuki, Ford, Sunline, Yamaha and Aero Vironment.

C. Oxygen Generation and Storage

Oxygen Generation

The Norsk Hydro electrolyser plant is described in more detail in Annex IV. The plant will generate approximately 41 normalized cubic meters of oxygen gas per hour ($Nm^3\ hr^{-1}$).

Oxygen Storage

The storage system selection process is highly dependent on the end use of the stored gas. For oxygen, the likely storage system will be high pressure tanks either bought by the project or supplied by the end user. The main cost of oxygen production (not already covered by the costs of hydrogen production) is the compressor. Norsk Hydro advised that no client had used the oxygen generated from their electrolysers due to the prohibitive cost of compression and, to a lesser extent, storage.

Oxygen Filling System for Containers

Valves can be added to the Norsk oxygen storage system to enable dispensing the gas to either small or large tanks and subsequent delivery of oxygen by road for off-site, probably, in Kuba-Khachmas districts. This may represent the lowest cost option, as the only addition to the plant is a few valves supplied by Norsk, and purchase of small oxygen tank containers, which can be recycled.

Oxygen Delivery

It is likely that oxygen will be delivered in small pressurized tanks by truck to the site of end-use, probably to Kuba and Khachmas districts.

D. Electrolyser Site Layout

A recommended site layout and positions of key plant are included in the Norsk Hydro quotation. Other details such as parking, housing, etc. must be worked out with the hydropower plant operations as facilities for the activities associated with the hydrogen generation plant may already be sufficient.

E. Additional Operational Data

Other Operating Norsk Hydro Electrolysers

In China, Air Products are running a Norsk hydrogen generating plant used for gas purification, and in Greenock, Scotland there is another. In England, Norsk has installations on Heysham II nuclear station. In France, Norsk delivered 2 electrolysers to EDF (Electricite de France) intended for use as energy storage/carrier on a nuclear power plant. Norsk have several installations in Turkey and in Istanbul the Besler Corp. has one operating electrolyser with a capacity 150 $Nm^3 hr^{-1}$. The electrolyser plant will operate for one year under guarantee.

III. USAGE OPTIONS FOR HYDROGEN AND OXYGEN PRODUCED AT NIYAZABAD PLANT

A. Uses for Hydrogen

Kuba-Khachmas region is situated in the Northern Azerbaijan and borders with Russian Federation. This is one of the large agricultural regions and recreation centers of the republic due to its situation in the Caspian coastal zone. The population here is basically involved in agricultural industry. According to newly adopted governmental program on the development of tourism and recreational zones one of the 5 tourist routes is situated in this region.

Based on the above mentioned we can say that in Kuba-Khachmas zone, there will be significant demand for hydrogen and oxygen for use in various purposes.

Potential uses for the hydrogen produced at Niyazoba plant can be considered as:

- Fuel cell operation and testing (vehicles, combined heat-power, portable equipment)
- Electric power generator cooling
- Fibre optics production
- Semiconductor fabrication
- Electronic fabrication
- Argon and nitrogen purification
- Metals processing e.g. steel heat treatment
- Chemical feed stock
- Pharmaceutical feed stock
- Float glass processing
- Fat and oil hydrogenation
- Multiple gas chromatograph support
- Meteorological balloons
- Fixation of nitrogen from air
- Methanol production
- Hydrodealkylation
- Hydrocracking
- Hydrodesulphyrization
- Metallic ore reduction
- Superconductivity study (liquid hydrogen)

Hydrogen gas may also be used in converted gas water heaters, cooking burners or as an admixture fuel in conventional generators. For hydrogen use in electricity generation units (gen-sets), simple adjustments may be made to the units: The throttle is adjusted until the motor runs at half speed using its intended fuel type and a small amount of hydrogen gas is introduced into the air intake until the motor reaches full speed. The addition of hydrogen gas into the air intake gives plenty of clean burning power without the problems usually associated with running pure hydrogen fuel. However, installation of gas cut off solenoids is essential incase the motor stalls. Hydrogen gas admixtures can save 50% of fuel costs and work on any engine without expensive carburetor or injector modifications.

Numerous benefits can be realized by using direct high purity hydrogen in a fuel cell. The applications that are amenable for direct hydrogen fuel sourcing include portable devices, backup power and several hydrogen energy station concepts. Fuel cells offer the potential for longer run times and higher power features in portable power applications such as cell phones and laptops. Backup power in the form of an uninterruptible power supply (UPS) is required when a highly reliable power source is critical to keep a business or equipment in operation without interruption even if grid power is lost. The significantly longer life of fuel cell systems could allow them to be used as replacements for battery systems that currently provide the needed primary or backup power for many of these applications. Appropriately designed fuel cells can produce electricity for commercial and residential power requirements while simultaneously providing heat. Supplying hydrogen directly to a fuel cell improves the efficiency of the fuel cell system. Although these technologies are not currently employed broadly, their widespread uptake is predicted in the next 5-10 years. For the proposed plant to provide hydrogen for fuel cells, ultra-pure hydrogen would be needed, requiring dryer and deoxidizer systems to be added to the plant.

B. Uses for Oxygen

Industrial

Most industrial uses of oxygen are based on the ability of oxygen to promote combustion. Increased efficiency and energy savings result from replacing or enriching air with oxygen, in steel (the first and largest area developed for oxygen applications), metallurgical, chemical processing, rocket fuel and glass applications. In the glass industry , oxygen/fuel combustion is used to reduce particulate and NOx emissions in melting operations. For metal fabrication, oxygen is burned with acetylene, propane, and other gases used in welding and cutting torches to provide a secure joint, stable fixture and fastening. In the pulp and paper industry, oxygen is used for pulp bleaching, black liquor oxidation and lime kiln enrichment. It is anticipated that in Kuba-Khachmas region there is a significant demand for oxygen for use in gas flames used for metal cutting.

In petroleum refineries, oxygen is often used to de-bottleneck sulphur recovery units (SRU). Sulphuric acid regeneration by oxygen enrichment of the combustion air can result in significant increases in plant capacity. Also, oxygen is often used to increase the capacity and conversion of a Fluid Catalytic Cracker (FCC) in a refinery. This is done by oxygen-enriching the combustion air to the regenerator and offers a very quick and economic means of boosting refinery profits.

As pure oxygen contains five times the concentration of oxygen in air, it can be used to provide ample oxygen to living systems that may be short of oxygen under normal atmospheric conditions. Such systems include biological wastewater treatment plants, rivers, lakes and fish farms.

Medical

In addition to industrial applications, oxygen is also recognized as an important component of respiratory aids in the medical field. As traditionally used for life saving applications where the patient is confined to the institution, oxygen has been supplied to hospitals through bulk tank installations, or larger cylinders. With recent advances promoting improved quality of life not just the saving of lives, patients can now return to leading relatively normal lives, their oxygen needs being supplied by lightweight storage cylinders. For example, the ‘Evasion’ lightweight cylinder (Air Products) incorporates an integrated pressure regulator and flow controller in a lightweight cylinder, allowing patients to use the cylinders in their own homes. The PA2 cylinder is a small lightweight cylinder of 2 litre capacity, with integral pressure and flow control, and a weight of only 3 kg. When this cylinder is mounted in a back pack it allows formerly housebound patients mobility for up to 5-8 hours.

IV. ECONOMIC ASSESSMENT

A. Plant Costs

A complete summary of all costs associated with the plant can be found in Annex VI.

Electrolyser Plant Costs

Norsk Hydro provided a detailed quote for an electrolyser plant and associated units. The total cost of the plant was approximately $998,638 and this quote included the provision of the elctrolyser, transformer, compressor, gas storage facility and engineering/project management. The costs cover hydrogen production, compression and storage, but only the costs of oxygen production. Costs of oxygen compression and storage add a further $302,617 to plant costs. Furthermore to increase the hydrogen storage capacity to the equivalent of 24 hours of production, $68,880 should be added. A breakdown of costs can be found in the table below.

Hydrogen Generating Electrolyser Plant Capital Costs

	Cost Per Unit in Currency of Purchase	% of Total Costs	Cost ($)+
Electrolyser*	NOK 3,300,000	50	499,319
Transformer	NOK 660,000	10	99,863
Compressor	NOK 1,452,000	22	219,700
Gas storage	NOK 660,000	10	99,863
Engineering, management, etc	NOK 528,000	8	79,891
TOTAL	**6,600,000**	**100**	**$998,638**
Oxygen Compressor	NOK 2,000,000	Optional Extraº	$302,617
Increased Hydrogen Storage (equivalent of 24 hr production)	NOK 450,000	Optional Extraº	$68,880

+Manat 4,600 = $1; NOK 6.609 = $1

*With control panel, water treatment, lye tank, scrubber and gas holder.

º Not recommended in the original Norsk Hydro quotation.

Electrolyser Transport Costs

The transport costs of the electrolyser system to Azerbaijan have been estimated at US$5.000. This estimate is based on a previous delivery and will need to be revised when the exact volume of plant, number of cases and shipping date are known.

Land Costs

The entire plant will require an area of approximately 15 x 11 m (including security fencing) for operation and gas storage. Additional car and truck parking will be required and the site layout will require planning once a map of the area has been delivered. An area of approximately 400 m^2 (0.0004 km^2) should be sufficient for all activities associated with this plant. Land costs are therefore expected to be $38,000 calculated using current exchange rates.

Building Costs

Building costs are expected to be in the order of thousands of dollars (≤ $15,000), since the unit comes with housing and requires little additional building. Materials costs which may be required are for car-parking and road construction. Limited manpower will be required to erect the unit and no additional buildings are foreseen at this time. The estimated plant costs are discussed and summarized.

B. Operating Costs

Personnel Costs

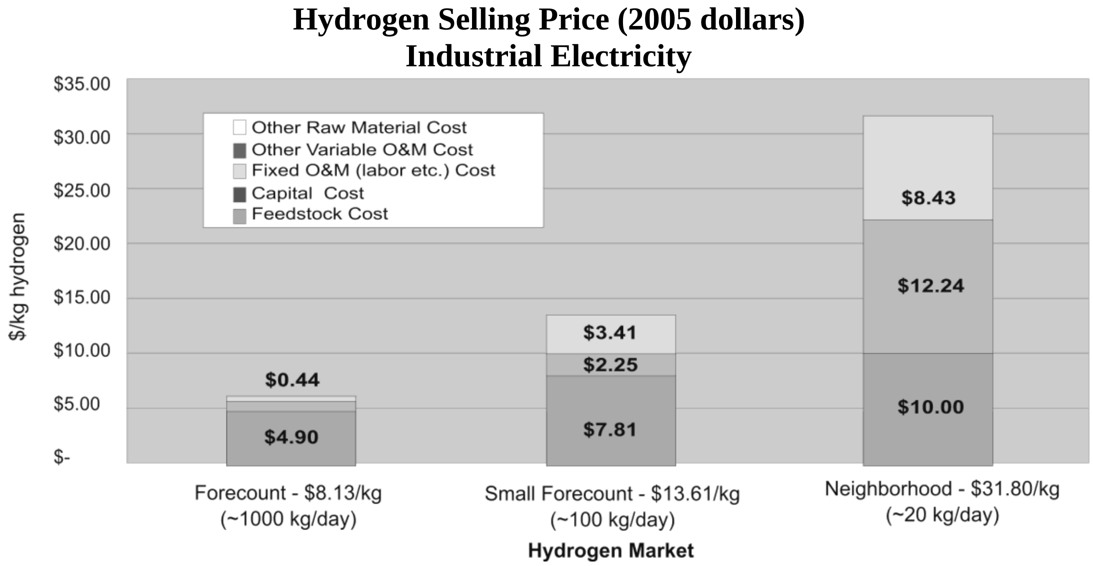
The plant is automatic and normally requires one skilled mechanic or electrician, part time ($1,800 per annum). Security provisions should also be made and an additional $1,200 per annum is budgeted to cover these costs. Hydrogen and/or oxygen gas production will result in additional personnel requirements to bottle the gases and deliver them to potential customers. It is estimated these tasks will require one trained person at a local salary of $1,500 per year. Personnel costs for the operation of the plant are therefore not expected to exceed $4,500 per annum.

Calculations of Hydrogen Production Costs

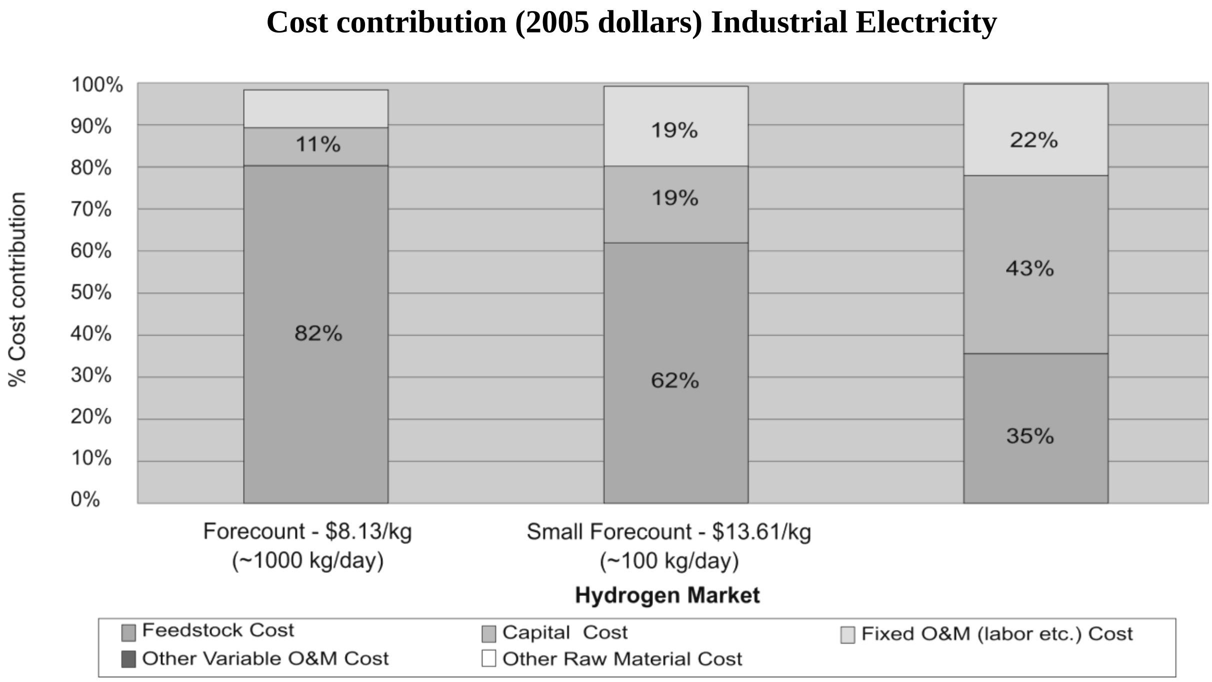
The cost of producing hydrogen via current electrolytic processes is largely dependent on the cost of electricity, the efficiencies of the systems, and the capital costs of the systems. In the NREL report by Ivy (2004) it was reported that for an ideal electrolyser system operating at 100% efficiency, electricity costs must be lower than 7.5 cents per kWh to produce hydrogen for less than $3.00/kg. This analysis demonstrated that regardless of any additional cost elements, electricity costs will be a major price contributor. Therefore, in the case of the Gudial chay hydrogen generator site, the availability of free electricity is an enormous advantage in terms of operating costs. The study compared costs for three systems which represented electrolysers for a small neighborhood (~ 20 kg/day), a small forecourt (~ 100 kg/day), and a larger forecourt (~ 1,000 kg/day). The Gudial chay plant size roughly falls within the middle category (≈ 170 kg/day). For hydrogen generators in the middle category, electricity represents 62% of the cost of the hydrogen while the capital costs were 19%. For all systems electricity price was a major contributor to hydrogen price, but for small-sized electrolysers, capital costs are more significant.

A comparison of costs between systems was also carried out by IVY. It is important to note that diminishing the electricity costs further (ideally to zero) clearly makes the Kuba-Khachmas economic case more attractive. A few factors differ between electrolysis cases, which will affect the costs. First, each system has different electrolyser system efficiencies. As a result, the systems will need different amount of electricity to make the same amount of hydrogen. Second, different electrolysers have different system lives. This analysis assumed an analysis period and plant life of 40 years. This time was chosen to be consistent with the USA Hydrogen Association (H2A) guidelines. However, electrolysers have a stack life between 5 and 15 years, so stacks from different manufacturers will need to be replaced at different intervals. The systems with the shorter system life will have higher capital costs.

The graph below indicates the hydrogen selling costs for the three cases. It also illustrates the different cost contributions for all three cases, along with the difference in cost contributions across the cases. Feedstock casts essentially represent electricity costs. For all three cases, the other raw material cost contribution and variable operating and maintenance costs are seen to be negligible. The other raw material cost contribution includes the KOH electrolyte, when applicable. The variable operating and maintenance costs include utility costs, process or de-mineralized water, cooling water and inert gas (needed for instruments and initial system pressurization).



This figure illustrates the driving costs for each of the three cases. In the most comparable case to Kuba-Khachmas (small forecourt case), the electricity cost contribution represents 62% of hydrogen selling prices. In all three cases electricity costs are a major driving factor in cost to consumers. The graph shows that as production is scaled up, electricity costs become more significant. If electricity costs are eliminated hydrogen production will provide a more economically attractive case.



The previous graph shows how dependent the electrolysis hydrogen costs are on electricity price. The cost of electricity and the system efficiencies are interrelated because either an increase in efficiency or a decrease in electricity costs will bring down the overall electricity cost contribution. However, the amount of the system efficiency can be increased is limited, and current industry goals are to reduce the energy requirement of the system to around 50 kWh/kg of hydrogen (a system efficiency of 78%), including compression of the hydrogen gas to 6,000 psig. While this increased efficiency will bring down the electrical cost contribution, it will not reduce the cost as much as a significant reduction in electricity price. As electrolyser technology improves, capital costs will become less of a factor, and the effect of higher electricity costs will be significant for all systems, regardless of size.

The major conclusion of this study was that in order for electrolysis to produce low-cost hydrogen, low cost electricity must be available. The Kuba-Khachmas project therefore offers an attractive long-term commercial opportunity since the electricity used to generate hydrogen may be provided free, due to a mismatch between the supply and demand of electricity generated by the hydropower station.

The costs for hydrogen produced at the plant site can be estimated based on the figures from Ivy (2004) and are presented in the table below together with the calculation input data. The production costs for hydrogen based on the electricity supply to the pant are low, assuming $1/kg hydrogen electricity costs, $2.25/kg capital cost and $1.70/kg operational and maintenance costs (estimated total cost: $4.15/kg hydrogen). In the case of zero electricity cost to generate hydrogen at Kuba-Khachmas, the estimated total cost is approximately $3.1/kg hydrogen. Compared to hydrogen costs quoted in the Ivy report, production costs at Niyazoba are lower by a factor of up to 10. This comparison indicates the potential economic advantages to be made through the sale of hydrogen generated at Niyazoba.

Hydrogen, oxygen and other fuel costs

	Cost in currency of Purchase	**Cost ($)⁺**
Electricity tariff	Population - 96 manat/kWh Industrial enterprises – 130 manat/kWh Commercial enterprises-250 manat/kWh	$0.0208 $0.0280 $0.054
Cost of hydropower electricity		
Natural gas	230 manat/m^3	$0.050
Liquid natural gas (LNG)	850 manat/liter	$0.184
Benzene 93	1,800 manat/liter	$0.390
Diesel fuel	1,200 manat/liter	$0.260
Estimated production cost of Kuba-Khachmas hydrogen (hydropower electricity tariff case)*	19,090 manat/kg	$4.15/kg
Estimated production cost of Kuba-Khachmas hydrogen (free electricity case)*	14,260 manat/kg	$3.10/kg

[+]Manat 4,600 = $1

***** Estimates based on calculations of hydrogen costs in Ivy (2004): Electricity costs based on the hydropower tariff are approximately $1.00 per kg hydrogen, capital costs account for $2.25/kg and operational and maintenance costs account for $1.70/kg. If electricity is supplied to the electrolyser at zero cost, costs are reduced to approximately $3.10/kg hydrogen.

<u>Additional Electrolyser Operating Materials and Costs</u>

All interconnecting piping and cables for the electrolyser are delivered by Norsk, but pipe supports and cable trays are to be bought by customer.

Maintenance cycles are approximately monthly for the compressor and longer for other plant components.

There are no foreseen service costs.

Management Costs Associated with Gas Production and Use

The costs associated with the gas management system of the hydrogen plant are summarized below. While the hydrogen management costs are considered imperative, costs associated with oxygen gas management may be considered optional in line with advice from Norsk Hydro. Norsk emphasized that oxygen production, compression and storage had yet to prove economic for any electrolyser customers to date. While many had enquired, none had opted for an oxygen management system; oxygen is vented at all their plants.

Gas management System Costs

The costs associated with the gas management system may be considered as storage and delivery. The total cost of hydrogen management is estimated to be $127,500. Total costs of the oxygen management are estimated at an additional $55,000. An estimated breakdown of cost for the system is presented in the table below.

Additional Gas Management System Costs

	Cost per unit in Currency of Purchase	**Number required by Hydrogen Project**	**Cost ($)[+]**
Truck (Middle Class)	44, 919000 manat	1	9,765
Truck (Large Class)	67,316400 manat	1	14,634
Hydrogen Gas Tanks	$550	180	99,000
Gas Transport (Driver)	8,740000 manat	2	1,900
(Per year)			
Estimated Gas Transport (Fuel)*		Per year	3,000
TOTAL COSTS			**$128, 299**
Oxygen Gas Tank	$550	100	55,000

[+] Manat 4.600 = 1 USD

* Based on 2 daily return trips to Kuba-Khachmas region with a vehicle fuel efficiency of 15 km per litre diesel fuel, 365 days per year.

Gas Delivery

A simple valve system can be installed on the main gas storage tanks to fill small discrete containers of 50 litres. These containers may then be transported by truck to the point of use. The estimated cost of this system per annum is $127,500 for hydrogen delivery only, and an additional $55,000 for oxygen to be included.

Cost at Point of Use

The cost associated with the use of the hydrogen and oxygen produced by the Niyazoba plant is not covered by this project. Consequently, the conversion of machinery to operate on hydrogen, connections to supply and any other costs will not be covered by this programme.

Hydrogen Education

The provision of education on the use of hydrogen and associated technologies will be an important aspect of this project. The education programme will consist of publicity and safety leaflets, a series of talks and discussion workshops, and a media campaign. It is envisaged that such an education programme will be led by ICHET in close conjunction with International Ecoenergy Academy, and with the support of Azerbaijan government, Kuba-Khachmas regional government, UNIDO, and the selected electrolyser plant supplier. The costs associated with such a programme will be covered by the project management costs associated with this project.

V. ENVIROMENTAL AND SOCIAL IMPACTS

Hydrogen, as fuel, can be used to produce electricity, power for vehicles, and heat for houses and other buildings. Since it is clean and renewable energy source, it can promote a healthy environment by reducing or eliminating harmful pollutants as otherwise would be emitted through other existing energy production technologies. As a result of the awareness on the environmental consequences of the present fossil fuel base technologies, a transition to a hydrogen-based economy has become an attractive option. Therefore, it is expected that in the long-term hydrogen will join electricity as a major energy carrier and that much of the hydrogen will be derived from renewable energy sources [Veziroglu, T.N. and Barbir, F, 1992].

The overall environmental impact of the Niyazoba hydropower-hydrogen cogeneration plant is expected to be positive. However, limited negative environmental impacts are considered below. The potential environmental and social improvements deliverable by the operational plant in terms of the elimination of air pollution emissions and the displacement of firewood far outweigh the minor and temporary negative impacts are discussed below. It is anticipated that 500 households (6,000 people) will benefit from the Niyazoba plant. At the same time, the project complies with important international conventions on environment protection (climate change, desertification, protection of ozone layer, etc.) Since this project will demonstrate the benefits of hydrogen generation from SHP in Azerbaijan, a favorable project outcome is expected to result in multi-site replication in the republic, perhaps on a large scale. The number of households and people advantaged indirectly through this project is therefore expected to rise over time. It is therefore anticipated that this initial projects will eventually lead to some of the broader social and environmental advances discussed below.

A. Environmental Impacts

General Construction Impacts
Minor construction impacts are expected as a result of the site development.

Hydropower Station Development and Operation
Hydro power has environmental impacts which are very different from those of fossil fuel power plants. Hydro-electric plants do not emit any of the standard atmospheric pollutants such as carbon dioxide given off by fossil fuel fired power plants. In this respect, hydro power is better than burning coal, oil or natural gas to produce electricity, as it does not contribute to global warming or acid rain. Similarly, hydro-electric power plants do not result in the risks of radioactive contamination associated with nuclear power plants.

The Niyazoba hydropower station is a middle head run of the river plant. The plant will have a dam to generate power. Since the river is situated on hillside there is no danger concerning flooding. Each station is expected to occupy an initial area of 0.0067 km^2 of farmland during construction of the site, and 0.04 km^2 farmland on completion. No settlement displacement will occur due to the plant and such run of the river hydro plants and reservoirs are neither a source of greenhouse gases, nor threaten habitat or rare ecosystem loss.

Other impact on the watershed may also be considered. Downstream from the dam, both the amount and quality of water in the river may change as a result of operating of the hydropower plant, and migratory fish may be prevented from migrating upstream to spawn. This impact can be reduced by controlling minimum flows downstream of a dam, and by creating fish ladders which allow fish to move upstream past the dam. Silt deposition patterns may also change; deposition may occur further upstream and change the path of the river while the river downstream of the dam is also deprived of silt which fertilizes the river′s flood-plain during high water periods.

Hydrogen Generation Plant Impacts

The environmental impacts of operating the hydrogen generation plant are estimated to be negligible. No fumes will be emitted to the air and only clean water will be emitted to water courses.

Global Climate Change

Hydrogen produced at the Niyazoba site will displace significant greenhouse gas (GHG) emissions. GHG, especially CO_2 and N_2O remain in atmosphere over a long time, up to 100 years and they influence radiation effect for long time, accordingly. As a result of these changes additional thermal effect and increase of atmosphere temperature happen. During the second half of the XX the annual air temperature on the geographical zones of Azerbaijan has increased by 0.5-0.8 °C. During that period the average annual temperature in the Kuba-Khachmas region has increased by 0.6 °C (M. Mansimov, 2003). Although there has been considerable focus in the international community on the development of an emissions trading framework, whereby foreign investment in programmes to reduce GHG emissions call results in sharing of the emissions-reduction credits, there are considerable difficulties in the inclusion of household stoves in the clean development mechanism (CDM) or similar mechanisms. On a practical level, it is very hard to include these emissions and therefore they are likely to be ignored through the conversion of local households to reliance on hydrogen as a fuel (either directly or via electricity consumption) GHG emissions will be reduced and the CDM will become more accurate.

Health Impacts

Residential use of wood and fossil fuel has traditionally been associated with combustion devices that produce substantial health-damaging pollution, exposing the users to dangerous levels of pollutants for many hours of the day. Such exposures have been linked to serious illnesses, including long-term cardio-respiratory illnesses and short-term increased susceptibility to lung infections (Kirkwood *et al.*, 1995).

According to the data of WHO 68% of diseases are caused by polluted air. The results of recent studies on atmosphere air have shown that sometime in several regions of Azerbaijan concentration of greenhouse gases (CO, CO_2, NO_x and hydrocarbons) in atmosphere air is 32 fold the maximum allowable concentration. Because of the lack of lead-free additives about 10% of petrol used in the republic contains tetra-ethyl-lead. The annual quantity of harmful emissions comes to 2000 tons (Report of the Ministry of Ecology and Natural Resources, 2001). It is reasonable that in the future one of the main users of the hydrogen produced at Niyazoba site would be transport. Over the past ten years, large scale epidemiological studies conducted in cities around the world demonstrated a consistent correlation between daily variations in ambient fine particulate matter (PM) mass concentrations and fluctuations in cardio- respiratory mortality and morbidity (Pope and Dockery, 1999). When sulphur in associated with this particles (adsorbed on the surface or in gaseous from as sulphur dioxide), PM is particularly effective at causing lung damage. Individuals with existing lung disease are found to be more susceptible to PM exposures with asthmatics and the elderly identified as being particularly at risk. Emissions from burning fossil fuels can result also in acid rain. Emissions of acid rain can be carried hundreds of kilometers from the source and remain in the atmosphere for days. In a number of regions where oil (kerosene) and wood devices are used as an indoor heating and cooking source, significant increase in atmospheric pollutants has been observed. The Niyazoba hydrogen generation project provides the opportunity to displace the emissions of thousand of domestic heathers in the Kuba-Khachmas area, improve the air quality and health of its residents.

B. Social Impacts

Impact of the Displacement of Firewood as a Fuel

In many region of Azerbaijan, there are social implications for the transition of fuel use from oil and wood to electricity. The greatest impact is on time budgets of family members assigned to gather biomass fuels. Displacement of other energy sources by hydrogen will enable those once responsible for fuel gathering to become more productive in other areas of their lives.

C. Safety Issues

Hydrogen Safety

A working knowledge of hydrogen gas safety is necessary before using the gas. If hydrogen space- heaters are to be introduced, awareness of the following is recommended:

- Installations should only be done by a qualified service person.
- Any changes to heather or its controls, or attempts to clean the catalytic pad can result in damage, defective operation, and may be dangerous.
- Any experiments with hydrogen fuel should be done outside.
- Hydrogen gas is odorless; you cannot smell a leak.
- Remember that hydrogen gas and air mixtures are potentially combustible and explosive over wide mixture ratios (4 to 75% hydrogen in air). Only pure gasses should be stored, never mixtures of hydrogen and air.

If hydrogen is to be stored, it must first be made safe to store. Hydrogen mixtures are not safe to store if the oxygen contamination is significant. Hydrogen has mach wider flammable and explosive limits compared to other fuels, especially in hydrogen- rich mixtures with air or oxygen. Hydrogen should never be stored unless it is well bellow the lower flammable limit (LFL). Normally, industry standards for storage safety call for well bellow 0.25 LFL, (or less than 1% oxygen in the hydrogen). To meet this standard, some way accurately measuring the oxygen contaminant in the hydrogen must be available.

Oxygen Safety

An excess of oxygen in air is very dangerous as it increases the combustibility of materials. More than 21% oxygen helps materials to burn (oxidize) better and faster and, coupled with the fact that the gas has neither odour nor colour, this makes an excess of oxygen in air dangerous. An increase of just 3% from the ambient oxygen concentration of 21% doubles the combustions velocity. By the time this figure reaches 40%, the combustions velocity of gases in contact with a spark or naked flame increases tenfold over ambient. Despite this, oxygen is commonly used gas and safe practice when working with and storing oxygen is well established. Some of precautions that may be taken to minimise the risk of using oxygen are listed bellow.

- provide adequate ventilation
- use oxygen level meters
- use two operators connected with a lifeline when entering confined space where there risk of too little oxygen or enrichment
- make sure all couplings of houses are gas – tight; use leak testing spray
- set correct pressures on control equipment and use the right nozzles
- wear appropriate clothing

- during prolonged breaks, remove hoses from confined spaces
- never use oxygen for use other than those for which the gas is intended :
- never blow working clothes clean with oxygen
- never use oxygen for pneumatic tools or spray-painting equipment
- never use oxygen for blowing piper system clean
- never use oxygen for ventilation or cooling
- always ensure that regulators and connections from the oxygen service are completely free from oil and grease, because oil and grease in contact with oxygen, especially at high pressures, can ignite explosively.

VI. CONCLUSIONS

The electrolyser technology and associated plant for the scale of plant purposed for Niyazoba can be sourced from a limited number of suppliers. These suppliers have significant experience in the field. While several technical options and configurations exist, it may be prudent to select a complete system to ensure compatibility of the entire system and ease of maintenance. A turnkey unit would probably reduce the personal and safety requirements of the immediate partners involved, increase guarantee cover and reduce overall costs. Guarantees for such units run one or two years of operations.

The most significant proportion of the project cost is purchase of plant. Plant costs very with supplier, but a low estimate is $998,638 for electrolyser costs, including hydrogen gas compression and storage. Gas management costs associated with the compression storage and delivery of hydrogen and oxygen gases are also significant. Increased hydrogen storage plus gas management prior to the point of end- use (transit storage and delivery facilities), adds a further $130,000. Gas management for oxygen is considered a cost prohibitive option by electrolyser suppliers, at in this case would add a further $350,000 to the plant costs. Compression in particular is an expensive processing stage. Land costs and fixed operational and maintenance costs are not a significant proportion of costs.

An economic analysis of hydrogen production costs indicates that in comparison with hydrogen produced in the USA, hydrogen generation at Niyazoba will be up to six times cheaper, particularly if the electricity is supplier at the zero cost to the electrolyser plant. Potential end users of the gases produced by the Niyazoba plant have been tentatively identified. These end-users are located in Kuba-Khachmas region as well as in Baku. It is anticipated that both medical are industrial users will be found in this areas.

It is expiated that there are limited negative environmental impacts of the site development. Indeed, the project has the potential to demonstrate positive environmental and social benefits, especially if hydrogen generation at small hydropower plants is adopted as a national policy and the experience derived from the Niyazoba pilot project well be used on wide scale throughout rural Azerbaijan. The benefits of the project are certainly in line with the aims of current national policies in Azerbaijan to promote clean energy generation, reduce greenhouse emissions and improve air quality.

The issue of safety is also an important consideration for this project, as are the twin aspects of education and public information. In order to provide a successful conclusion to this pilot project and promote wider application of similar hydrogen generation facilities, coordinating project information will be an important component of the overall project management. It will be important to secure the right partnership within the project and engage local authorities to support these activities.

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ANNEX I: Engineering Study Brief

A. Engineering report: This will include the design and the costing of the complete engineering system to produce hydrogen (and oxygen) using the excess electricity from the Hydropower plant, to store it, to fill the hydrogen (and oxygen) into containers for distribution customers by trucks. The system should include the necessary power conditioning, electrical controls, water supply, water purification, water supply controls, electrical and water connections, electrolyser(s), hydrogen storage, oxygen storage, hydrogen (and oxygen) filling systems for containers, and any all other systems needed, the plant layout, equipment an system specifications, cost breakdown for all the items, including the building for housing them, parking needs for trucks to transport hydrogen and oxygen containers, and for cars for operating personnel and visitors. The report should look into two alternatives:

(a) Utilizing the excess electricity most of the time over 24 hours.
(b) Utilizing the excess electricity only during the off-peak hours.

The report should also include an economical analysis of the cost of the hydrogen and oxygen produced to the consumer and comparison with the cost of oxygen and other fuels available locally now. The report should also include a section on economical and environmental benefits.

ANNEX II: Description of works related to SHP stage of the Project

The Gudialchay river system comprises 3 sections:

- flow formation zone (flowing zone)
- transit zone
- irrigation zone

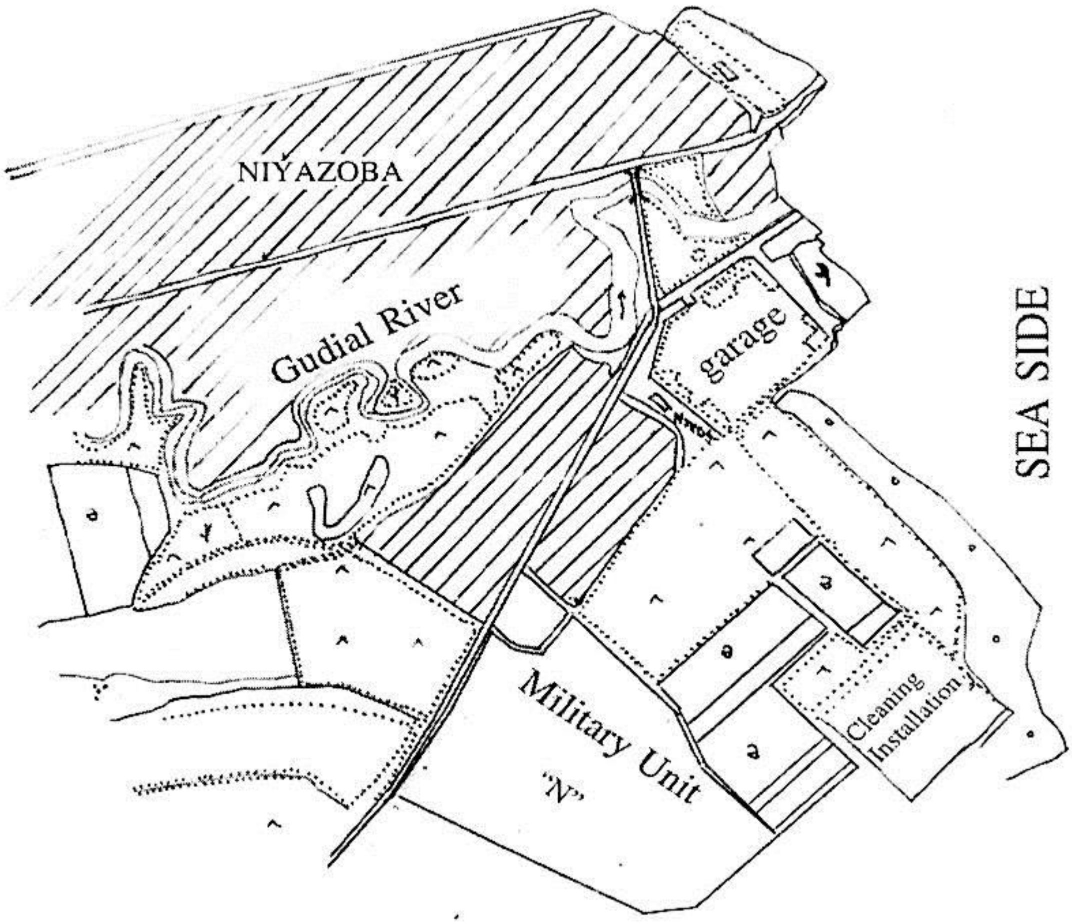

Fig.1. Map of Gudialchay River

Water from the river is taken in the leading hydropower plant on the given project . Therefore, it is possible to construct further several SHP of derivation type. For uninterrupted electricity generation two hydro aggregates will be installed as working and reserve units. The usage hours of designed capacity exceeds 8,000 hours. During the period of flood-time the second aggregate will be added to generate excess electricity. The head is accepted to be equal to H= 60:70m. One standard (model) project will be implemented for all SHP. The plant is located near the population center and is managed automatically. Ferro-concrete structures on the main constructions (building of SHP, sedimentation tanks, derivation canal, etc.) are made from prefabricated blocks. Electricity transmission lines are constructed.

The construction of proposed SHP is based on the following legislations of Azerbaijan:

- The Law “About Energetics” (1999)
- Normative land cost (Law , 2000)
- Law “About Environment Protection” (1999)
- Law “About Protection of Foreign Investment” (1999)
- Law “About Property” (2001)

The production base of SHP construction envisages:

- receipt of building materials, parts of hydropower and electro-technical equipment
- assortment and delivery of building materials to construction site
- rigging up equipment and reinforcement of metallic constructions
- production of prefabricated ferro-concrete constructions and elements
- concentration of machines and mechanisms and their regional use
- coordination of construction works

In accordance with the water head 2-3 kinds of aggregates will be chosen depending on water consumption. If the SHP is constructed near the population centers the head of SHP will be varied within 60-70 m. Francis turbines (radial-axial) are suitable for such head. Water consumption does not exceed 2 m/s, that means that the diameter of working wheels of turbine will not exceed 50 sm. Taking into account that the given value of consumption remains unchangeable during the year (P=95%) and the head is practically continuous, there is no necessity for the regulation of turbine capacity.

Gudialchay

The cost of the following works will be included to the SHP construction budget:

- preparatory works
- key constructions
- production base
- transportation management
- access roads and highways
- energy supply and distribution lines
- dwelling houses for builders and serving personnel

- water supply and canalization
- personnel training
- salaries of administration personnel and supervision
- project related researches
- cost of temporary and continuous works on land allotment
- dam rehabilitation cost

Preparatory works include:

- allotment of land under construction
- geodesic works
- construction layout
- dislocation of construction subdivisions

In the preliminary stage the cost of preparation works is expected to be 3% of the basic construction cost. Production base is associated with the delivery of ferro-concrete materials and metallic construction's assembling. Transportation management and auxiliary equipment is associated with creating a park of necessary machines and mechanisms for construction works.

Energy transmission and distribution lines from SHP to consumption points include:

- construction of energy transmission lines
- mounting control counters

Dwelling houses for builders and serving personnel includes:

- dismountable (prefabricated) one-storey houses for builders
- stone houses for operating personnel

Water supply and canalization are provided for construction site and further operational area. It is envisaged to take water from river for construction needs. Water for drinking needs will be centralized and stored in special tankers. A well to be sunk will be a source of domestic water. Canalization in the site is local with cesspool. An obligatory sanitary treatment is provided also. Personnel training will be carried out to train engineering-technical personnel. The cost is expected to be 0.5% of the cost of basic construction. Salaries of administration and supervising personnel will amount to 1% of the basic construction costs. The cost of project related researches is expected to be 2% of the basic construction costs. In the lack of concrete land costs, land expenses may be associated with income. For SHP with middle capacity of 1,000 kW at cost of $0.02 per 1 kW/h an annual income will amount approximately to $30,000. Expenses to rehabilitate a dam are associated with the necessity of maintaining in the leading canal a tractor of DT type to exploit a river-bed of the channel and reconstruct the dam broken after mud stream. Economic analysis of SHP construction includes main paragraphs of cost summary, which particularly includes the following initial data:

According to the data of firm "ASES" (Azerbaijan Hydro Electric Stations) a specific cost of 1kW of SHP of 1,000 kW capacity is equal to $1,800.

The expenses associated with the SHP exploitation include:

- exploitation cost
- electricity grid costs
- governmental taxes
- percent rate of credits

Annual cost of SHP exploitation, comprising 3% of the whole investment, includes:

- serving personnel salaries – 0.9% of investment

- amortization deduction for current and capital repairs – 0.6% of investment
- deduction for renewal (reconstruction) – 1.5% of investment

Cost of grids includes:

- losses in energy transmission lines – 2% of gross income
- individual expenses – 1%

The cost of the following works will be included to the SHP construction budget:

- preparatory works
- key constructions
- production base
- transportation management
- access roads and highways
- energy supply and distribution lines
- dwelling houses for builders and serving personnel
- water supply and canalization
- personnel training
- salaries of administration personnel and supervision
- project related researches
- cost of temporary and continuous works on land allotment
- dam construction cost

Cost summary

Small Hydro-Power Plant	Capacity, kW	Cost mln. US$
First station	1,000	1.8
Second station	1,000	1.4
TOTAL		32

ANNEX III: Main technical characteristics of hydro-aggregates needed for small hydro-power plants (SHPs) [Company INSET, St. Petersburg, Russia]

Francis turbines will be used in SHP. Francis turbines are used primarily for medium heads and large flows. Their special hydraulic characteristics enable relatively high-speed compact units, right up to the highest power outputs.

Hydro-aggregates with propeller turbines

Parameters	Type of hydro-aggregates				
	HA 1	HA 8	HA 13	Pr 15	Pr 30
Capacity, kWt	100-330	150-1800	50-200	up to 130.0	up to 150.0
Head, m	3.5-9.0	6.0-22.0	2.0-5.0	2.0-12.0	4.0-18.0
Consumption, m^3/s	2.3-6.2	2.5-11.0	23-5.0	0.44-1.5	0.38-1.1
Nominal tension, B	400	400 6,000 10,000	400	230/400	230/400
Nominal current cycle, hertz	50 ±2.5	50 ±2.5	50 ±2.5	50 ±2.5	50 ±2.5

Hydro-aggregates with radial-axial turbines

Parameters	Type of hydro-aggregates			
	HA 2	HA 4	HA 9	HA 11
Capacity, kWt	up to 950	550	3300	5600
Head, m	30-100	25-55	70-120	100-160
Consumption, m^3/s	0.4-1.25	0.4-1.3	0.6-3.2	1.5-4.0
Nominal tension, B	400 & 6,000	400 & 6,000	6,000 & 1000	6,000 & 10,000
Nominal current cycle, hertz	50 ±2.5	50 ±2.5	50 ±2.5	50 ±2.5

Hydro-aggregates with scoop turbines

Parameters	Type of hydro-aggregates	
	HA 5	HA 10
Capacity, kWt	145-620	290-3300
Head, m	150-250	200-450
Consumption, m^3/s	0.17-0.32	0.19-0.90
Nominal tension, B	400 & 6,000	400; 6,000 & 10,000
Nominal current cycle, hertz	50 ±2.5	50 ±2.5

Complete delivery, overall characteristics and cost of SHP with propeller and diagonal turbines

No	Name	Overall dimensions in packing, mm	Mass in packing, kg	Cost, in roubles
1.	SHP 10 Pr (15 Pr)			180000
1.1.	• Energy block	2000 x 700 x 650	250	
1.2.	• Automatic regulation device (ARD-10)	800 x 300 x 750	95	
1.3.	• Control switchboard	480 x 300 x 700	50	
1.4.	• Water taking device	1000 x 750 x 600	50	
2.	SHP 50 Pr			890000
2.1.	• Energy block	3970 x 1000 x 740	1600	
2.2.	• Automatic regulation device (ARD-50M)	730 x 905 x 1905	260	
2.3.	• Block of ballast load	1320 x 490 x 745	250	

Complete delivery, characteristics and cost of hydro-aggregates for SHP

No	Name	Mass, kg								
		HA-1	HA-13	HA-8	HA-2	HA-4	HA-9	HA-11	HA-5	HA-10
1	Hydro-turbine with propeller working wheel	3980	3720	7000	-----	-----	-------	-----	------	-------
2	Hydro-turbine with radial-axial working wheel	---	---	---	1300	1350	3300	4400	---	---
3	Hydro-turbine with scoop working wheel	----	----	----	----	----	-----	----	2200	5000
4	Angle multiplicator	1430	----	----	-----	------	-----	------	-----	-----
5	Anti-acceleration device	1850		1850	------	------	------	------	-----	-----
6	Generator (depending on capacity	1320-2600	350-1300	2600-3400	2000-2600	1500-2400	3000-13000	5000-28000	2500-3900	10000-25000
7	Automated management system (AMS)	100	100	100	100	100	120	200	100	200
8	Pipe and diffuser	---	----	----	400	400	600	700	----	----
9	Approximate cost per 1 kWt set capacity	12500-22500 rouble for aggr. about 80-300 kWt capacity		8000-11000 rouble for aggr. about 500 kWt capacity	7000-10500 rouble for aggr. about 400 kWt		7000-8500 rouble for aggr. about 1000 kWt		7000-10500 rouble for aggr. about 400 kWt	

[+] Rouble 28 = $1

ANNEX IV: NIYAZOBA PROJECT BACKGROUND

A. Project Context in Azerbaijan

Azerbaijan is one of the oldest oil producing countries of the world. It has an area of about 86.6 thousand square kilometers and population of 8.2 million. By the 1900s Azerbaijan was the world's biggest oil producing province. In the beginning of the century Azerbaijan shared about 20% of oil extraction in the World. The developing oil industry was in need of electric energy. In 1900, the construction of two power stations were started in Azerbaijan, in Baku. In 1901, in the Bibi-Eybat enterprise the first power station began to operate. This date can be considered as the beginning of foundation of the electric energy industry in Azerbaijan. Thus, power engineering in Azerbaijan was developed earlier than in other Transcaucasian republics as well as in the Near and Middle East.

During the Soviet period, Azerbaijan held a leading oil production role among the other states of USSR. Huge energy resources of the republic have created salutary conditions for the development of this branch.

The end of XX century is famous with political and economical processes that led to fundamental changes. Azerbaijan people achieved independence and government sovereignty.

The political instability occurred at the beginning of 90-ties has negatively affected on countries economy, including all components of energy sector. The conflict with Armenia had a negative impact on Azerbaijan power industry. Electricity transmission lines in some of regions were broken. Reconstruction of power stations needed significant investment. The lack of generating capacity and low efficiency of the taken measures in combination with the discrepancy of available total generation power to energy consumption became a key hindrance in revival of the republic economy.

After collapse of the former Soviet Union, energy sector's output in Azerbaijan has dropped by 25-30% that led to both insufficient supply and restriction in electric energy consumption. Long intervals have occurred in energy supply of whole regions.

The key goal of government energy policy was to increase electric energy generation and the country's energy supply, accordingly.

In 1994-1995 years owing to technical assistance of the European Union the work "Azerbaijan Republic government's advice on energy sector development" was fulfilled.
The work considered that investment in the first place is necessary for:

- rehabilitation of operating equipment capacity through the capital repairs and replacement of spares;
- reconstruction of a number of HPP (hydro power plants), SRTPP for replacement of the basic equipment, used 30-40 years, with modern economic equipment;
- construction of small hydro power plants, especially in the far distance of large energy systems and replacement of the old insecure equipment;

  The government started to carry out several measures, related to the new political actions, including:
- adopting a new law on electric energy
- creation of key commission for energy sector and development of methodology on establishment of electricity tariffs

- development of a strategy on privatization of the production and distributing organizations

At present in Azerbaijan the total volume of the generated energy, its transfer and distribution is carried our by “Azerenergy” JSC. “Azerenergy” conducts operations on energy systems’ equipment, transfer and sale of electric and thermal energy, as well as all kinds of repair services, scientific research works and designing of energy systems’ objects.

The total capacity of energy system is around 5,000 mW. This includes three condensation thermal electric stations, of which total capacity comes to 75% of system’s generating capacity, 5 thermal electric centers with 10% capacity, that produce electric and thermal energy and 5 hydroelectric stations, totaling 18% of set capacity.

The general technical state of electric energy system is characterized as: 11% of the system’s total capacity. The units being under operation over 40 years make half of a total capacity of all hydro electric stations. About 30% of capacity of the republic’s thermal electric stations fall on the share of either obsolete or operating over 30 years equipment. During last years as result of continuous operations under reduction of the capital repairs’ volume even the grade of comparatively new units have dropped. As a result, the capacity of stations has descended by 25-30%, that led to the chronic lack of energy supply and shortage in energy consumption. Continuous intervals have emerged in energy supply of many regions. People are forced to use forests, because of prolonged energy shortage in a number of regions, situated far from energy generating centers, where electricity serves as the only kind of the energy that they use.

A problem of supplying energy demand through SHP instead of the equipment put into operation during the last decades is of great importance to ensure the republic’s energy security. Hydro-energy resources of Azerbaijan are not used fully.

Potential of Azerbaijan hydro-resources for SHP.

Azerbaijan Republic has considerable resources for SHP. According to the data of feasibility studies carried out by International Ecoenergy Academy and “Azerenergy” JSC, it is established that the technical potentiality of small hydro-energy is evaluated in 4,900 mln. kW/hour, but the economic efficiency of the use of their resources in SHP may be assessed around 1,700 mln. kW/hour in volume of annual generation.

Currently 8-10% of the mentioned hydro-resource potential are used in operating plants. According to evaluations SHPs installed on individual regions will provide additional energy generation in an amount of 625 GW/h that will allow to economize 2500 tons of fuel and to reduce atmosphere emissions in a volume of 116.5 thousand tons of CO_2.

Azerbaijan government has demonstrated serious interest to Climate Change problems. According to Azerbaijan President’s decree from 30 April of 1997 the State Commission on Climate Change was established. The Commission comprises 14 members.

In accordance with the measures on performing Azerbaijan commitments to international agreements the given project will promote efforts on reducing the negative impact of climate changes.

In the Decree of the President of the Republic of Azerbaijan Ilham Aliyev “On measures for acceleration of social and economic development in the Republic of Azerbaijan” of November 24, 2003 it is stated “prepare and submit to the President of the Republic of Azerbaijan appropriate proposals on the use and development of alternative energy resources applicable in the world practice (solar, wind, thermal waters and small hydropower stations) in the country." Azerbaijan government pays a great attention to small SHP use to implement this policy in the process of energy generating systems' reconstruction. In order to promote clean energy generation in rural areas and improve the environment, plans were made to develop more environmentally sustainable SHP with the aim of replacing fuel wood with electricity in the regions where abundant small hydro resources exist. The main purpose of this project is to use existing hydro-resources at Small Hydropower Plants (SHP) to cover increasing energy demand in Kuba-Khachmas region. The experience derived from Niyazoba SHP will be used in other regions of the Republic. Concrete attention in the project will be paid to the coordination of works with both the active and planned national as well as international participants in the project.

The practice of many countries, working in this direction will be used during implementation of the project. In this respect the active and planned projects, dealing with use of this kind of power for regional energy supply purposes in Turkey, China and other countries should be mentioned especially.

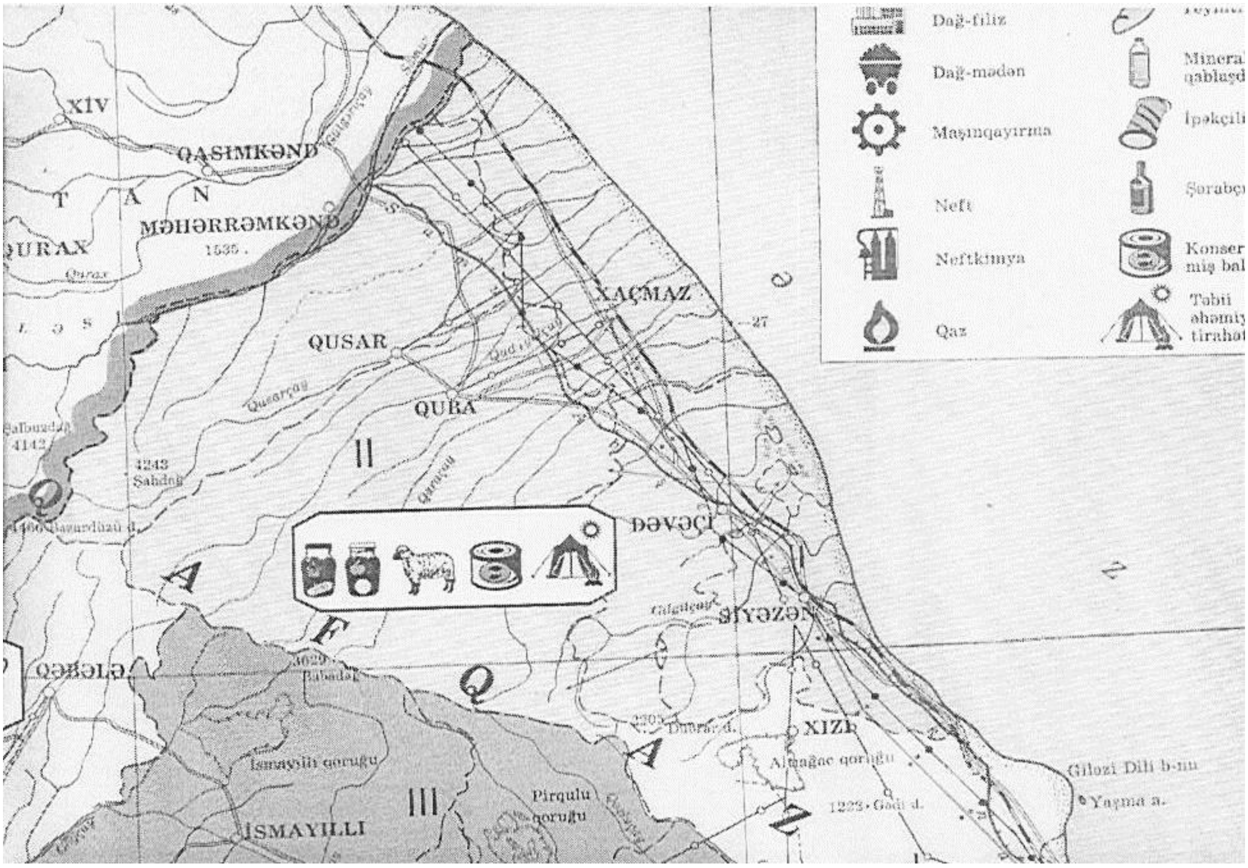

Fig. 2. Map of Kuba-Khachmas region

The proven success of such policies demonstrates that similar movements to introduce clean fuels and technologies such as hydrogen and hydrogen burners are also possible in the future.

This project will be planed and co-funded by the *UNIDO International Centre for Hydrogen Energy Center Technologies* (UNIDO-ICHET) based in Istanbul, Turkey. The proposed hydrogen generation facility will be situated at the Niyazoba hydropower station in the Kuba-

Khachmas region. The project aims to demonstrate the potential of using hydrogen to store the energy generated by intermittent renewable sources such as hydropower, in Azerbaijan. The Azerbaijan government has expressed interest in the prospects for hydrogen energy as an enabling technology for increasing the efficiency of SHP.

Unlike hydrocarbon-based fuels, hydrogen produces no harmful by-products upon combustion. Only energy and clean water are produced when hydrogen is combined with oxygen in a fuel cell. Hydrogen also represents a means of storing grid power (which is otherwise technically challenging) as a fuel. In a stand alone renewable energy system, the electrical supply rarely matches the loads, since the primary energy sources are weather dependent. Batteries are able to overcome this mismatch over short periods, but beyond about four days of storage capacity, they become expensive, bulky and inefficient. Hydrogen on the other hand, offers a method of longer -term or large- scale energy storage, achievable at a lower cost and with a smaller physical footprint. When there is a surplus of electricity from the renewable sources, hydrogen can be produced from the electrolysis of water and stored for later use. At times when there is a shortfall of power from the renewable sources, the stored hydrogen can be converted back to water via combustion in an electricity generating device (such as fuel cells), releasing electricity on demand. The production and consumption of hydrogen of is thus used as a load balancing mechanism. Hydrogen therefore combines the needs of balancing supply and demand on the electricity grid with providing fuel for either vehicles or domestic heating system, among other potential hydrogen applications. Hydrogen (produced using renewable power sources) in the energy medium that promises a pollution-free energy system for the future. In Azerbaijan, such relatively clean energy generation may provide a mach needed energy solution to prevent environmental degradation.

B. Rationale for a hydropower- Hydrogen Cogeneration Plant

In stand- alone renewable energy system, the electrical supply rarely matches the loads, since the primary energy sources are entirely development upon the weather. As supply and demand varies, hydrogen provides an excellent means of chemical energy storage, and can be used to store the energy produced by a renewable energy system. Renewable system may therefore be designed to exceed community energy needs when running at optimum level. The surplus energy can be used to produce hydrogen through water electrolysis. The hydrogen produced will be compressed and stored in a gas storage vessel and will be available when needed. Additional surplus energy can be solid in the market. When the renewable resources are not available –i.e. when there is too little or to mach wind, sun, wave action or water –the hydrogen can be used in a fuel cell and a hydrogen generation to produce power.

Hydrogen is thus an important enabler of renewable energy technologies.

C. Technical Aspects of Hydrogen Generation

Hydrogen is produced via electrolysis by passing electricity through two electrodes in water. The water molecule is split and produced oxygen at the anode and hydrogen at the cathode. Three types of industrial electrolysis units are being produced today. Two involve an aqueous solution of potassium hydroxide (KOH), which is used because of its high conductivity, and are referred to as alkaline electrolysers. These units can be either unipolar or bipolar. The unipolar electrolyser resembles a tank and has electrodes connected in parallel. A membrane is placed between the cathode and anode, which separate the hydrogen and oxygen as the gasses are produced, but allows the transfer of ions. The bipolar design resembles a filter press. Electrolysis cells are connected in series, and hydrogen is produced on one side of the cell, oxygen on the other. Again, a membrane separates the electrodes. The third type of electrolysis unit is a Solid Polymer Electrolyte (SPE) electrolyser. These systems are also referred to as PEM or Proton Exchange Membrane electrolysers. In this unit the electrolyte is a solid ion conducting membrane allows the H+ ion to transfer from the anode side of the membrane to the cathode side, were it forms hydrogen. The SPE membrane also serves to separate the hydrogen and oxygen gasses, as oxygen is produced at the anode on one side of the membrane and hydrogen is produced on the opposite side of the membrane.

D. Existing Manufactures of Industrial Electrolysers.

Norsk Hydro makes an electrolyser large enough to be considered a forecourt-sized system. Alkaline producers Teledyne and Stuart manufacture systems in the small neighborhood, neighborhood and small forecourt range, and Avalence′s small unipolar alkaline electrolysers are currently only sized for the home and small neighborhood. In contrast, Proton Exchange membrane (PEM) electrolysis units, produced by proton, are only sized for the home or small neighborhood system. This is a typical trend in the industry to day as the high capital costs of PEM units limit their current viability in large hydrogen production market, while alkaline units, with their lower capital costs, can produce across a range of hydrogen capacities. Additionally, the categories were used to allow.

E. Facts about Norsk Hydro

Norsk Hydro is the second largest power producer in Norway, with an annual normal production of 9 TWh. All energy produced by Norsk Hydro is renewable and most is produced at around 20 hydroelectric power plants. Norsk Hydro has built many electrolysers around the world, most recently at Utsira (inaugurated 1 July 2004). Utsira is a small island community with some 220 inhabitants, located approximately 18 kilometers off the west coasts of Norway.

Utsira is the world’s first full-scale autonomous, renewable energy supply system based on a combination of wind power and hydrogen. The purpose of the project is to demonstrate how renewable energy can provide a safe and efficient energy supply to remote areas were there is a plentiful source of renewable energy and/or insufficient infrastructure. The autonomous system includes 10 households, whose entire energy demand will be exclusively provided by renewable sources. In combination, wind power and hydrogen will be able to provide a continuous and viable supply of energy to the community. A picture bellow depicts the plant.

The electrolyser

An electrolyser is a device that produces hydrogen and oxygen by splitting water molecules by means of electricity. The gases are produced when electric current flows from an anode to a cathode through water mixed with lye (electrolyte). The electrolyte is used to optimize electrical conductivity.

Hydrogen power production

Power is produced from hydrogen by a 10 kW fuel cell and a 55 kW hydrogen combustion generator. The fuel cell produced power through a chemical reaction: energy is released from the hydrogen when it reacts with the oxygen in the air.

Hydrogen storage

The hydrogen is produced by the electrolyser is compressed and stored in a container that can hold up to 2400Nm^3 (normal cubic meters) of hydrogen gas. This is sufficient for two full days of energy supply to the households in the autonomous system.

Grid stabilization

This unit contains a flywheel with a storage capacity of 5kWh. It helps to maintain a stable power supply from the plant to the grid, in combination with the additional grid stabilizing equipment.

ANNEX V: INDEPENDENT COMPARISION OF ELECTROLYSERS (Ivy, US National Renewable Energy Laboratory [NREL], 2004)

Manufacturer Model	**Technology**	**Hydrogen Production Rate**				**Hydrogen product pressure**	**Energy Requirement**		**Power required for max H_2 production**	**H_2 Purity %**	**Life time years**
		Nm3/hr		Kg/hr		psig	kWh/ Nm3	kWh/ kg	kW		
		min	max	min	max						
Avalence Hydrofiler 15	**Unpolar Alkaline**		**0.4**		**0.04**	**Up to 10,000 psig**	**5.0**[2]	**55.6**	**2**	**99.7**	
Avalence Hydrofiler 50	**Unpolar Alkaline**		**1.5**		**0.1**	**Up to 10,000 psig**	**4.7**[2]	**51.8**	**7**	**99.7**	
Avalence Hydrofiler 175	**Unpolar Alkaline**		**5**		**0.4**	**Up to 10,000 psig**	**5.0**[3]	**55.6**	**25**	**99.7**	
Norsk Atmospheric Type No5010(4000AmpDc)	**Bipolar Alkaline**	**0**	**50**	**0**	**4.5**	**0.3**	**4.8**	**53.4**	**240**	**99.9=0.1**	**7-10**
Norsk Atmospheric Type No5010(5150AmpDc)	**Bipolar Alkaline**	**0**	**50**	**0**	**4.5**	**0.3**	**4.8**	**53.4**	**240**	**99.9=0.1**	**7-10**
Norsk Atmospheric Type No5020(4000AmpDc)	**Bipolar Alkaline**	**50**	**150**	**4.5**	**13.5**	**0.3**	**4.8**	**53.4**	**720**	**99.9=0.1**	**7-10**
Norsk Atmospheric Type No5020(5150AmpDc)	**Bipolar Alkaline**	**50**	**150**	**4.5**	**13.5**	**0.3**	**4.8**	**53.4**	**720**	**99.9=0.1**	**7-10**
Norsk Atmospheric Type No5030(4000AmpDc)	**Bipolar Alkaline**	**150**	**300**	**13.5**	**27.0**	**0.3**	**4.8**	**53.4**	**1440**	**99.9=0.1**	**7-10**
Norsk Atmospheric Type No5030(5150AmpDc)	**Bipolar Alkaline**	**150**	**300**	**13.5**	**27.0**	**0.3**	**4.8**	**53.4**	**1440**	**99.9=0.1**	**7-10**

Manufacturer Model	**Technology**	**Hydrogen Production Rate**				**Hydrogen product pressure**	**Energy Requirement**		**Power required for max H_2 production**	**H_2 Purity %**	**Life time years**
		Nm3/hr		Kg/hr		psig	kWh/Nm3	kWh /kg	kW		
		min	max	min	max						
Norsk Atmospheric Type No5040(4000AmpDc)	**Bipolar Alkaline**	**300**	**377**	**27.0**	**33.9**	**0.3**	**4.8**	**53.4**	**1810**	**99.9=0.1**	**7-10**
Norsk Atmospheric Type No5040(5150AmpDc)	**Bipolar Alkaline**	**300**	**485**	**27.0**	**43.5**	**0.3**	**4.8**	**53.4**	**2328**	**99.9=0.1**	**7-10**
Norsk HPE 10	**Bipolar Alkaline**		**10**		**0.9**	**232**	**4.8**[6]	**53.4**	**48**	**99.8**	**7-10**
Norsk HPE12	**Bipolar Alkaline**		**12**		**1.1**	**232**	**4.8**[6]	**53.4**	**58**	**99.8**	**7-10**
Norsk HPE 16	**Bipolar Alkaline**		**16**		**1.4**	**232**	**4.8**[6]	**53.4**	**77**	**99.8**	**7-10**
Norsk HPE 20	**Bipolar Alkaline**		**20**		**1.8**	**233**	**4.8**[6]	**53.4**	**96**	**99.8**	**7-10**
Norsk HPE 24	**Bipolar Alkaline**		**24**		**2.2**	**232**	**4.8**[6]	**53.4**	**115**	**99.8**	**7-10**
Norsk HPE 30	**Bipolar Alkaline**		**30**		**2.7**	**232**	**4.8**[6]	**53.4**	**144**	**99.8**	**7-10**
Norsk HPE 40	**Bipolar Alkaline**		**40**		**3.5**	**232**	**4.8**[6]	**53.4**	**192**	**99.8**	**7-10**

Norsk HPE 50	**Bipolar Alkaline**		**50**		**4.5**	**232**	**4.8**[6]	**53.4**	**240**	**99.8**	**7-10**
Norsk HPE 60	**Bipolar Alkaline**		**50**		**5.4**	**232**	**4.8**[6]	**53.4**	**288**	**99.8**	**7-10**
Proton HOGEN H Series	**PEM**	**0**	**6**	**0**	**0.5**	**218**	**6.3**	**70.1**	**38**	**99.999**	
Proton HOGEN 20	**PEM**		**0.5**		**0.04**	**200**	**5.6**	**62.3**	**3**	**99.999**	**5-7**
Proton HOGEN 40	**PEM**		**1**		**0.1**	**200**	**5.6**	**62.3**	**6**	**99.999**	**5-7**
Proton HOGEN 380	**PEM**		**10**		**0.9**	**200**	**6.3**	**70.1**	**63**	**99.999**	**5-7**
Stuart IMET 1000,1 cell stack, 1000 cm^3	**Bipolar Alkaline**	**3**	**5**	**0.3**	**0.4**	**360**	**4.8**	**53.4**	**24**	**99.997**	**10**
Stuart IMET 1000,2 cell stack, 1000 cm^3	**Bipolar Alkaline**	**16**	**30**	**1.4**	**2.7**	**360**	**4.8**	**53.4**	**144**	**99.997**	**10**

Manufacturer Model	**Technology**	**Hydrogen Production Rate**				**Hydrogen product pressure**	**Energy Requirement**		**Power required for max H_2 production**	**H_2 Purity %**	**Life time years**
		Nm3/hr		Kg/hr							
		min	max	min	max	psig	kWh/Nm3	kWh/kg	kW		
Stuart IMET 1000, 3 cell stack, 1000 cm^3	**Bipolar Alkaline**	**31**	**45**	**2.8**	**4.0**	**360**	**4.8**	**53.4**	**216**	**99.997**	**10**
Stuart IMET 1000, 4 cell stack, 1000 cm^3	**Bipolar Alkaline**	**64**	**50**	**5.8**	**5.4**	**360**	**4.8**	**53.4**	**288**	**99.997**	**10**
Stuart IMET 1000, 6 cell stack, 1000 cm^3	**Bipolar Alkaline**		**90**		**8.1**	**360**	**4.8**	**53.4**	**360**	**99.997**	**10**
Stuart IMET 300, 1 cell stack, 300 cm^3	**Bipolar Alkaline**	**1**	**3**	**0.1**	**0.3**	**360**	**4.9**	**54.5**	**15**	**99.997**	**10**
Teledyne EC-500	**Bipolar Alkaline**		**28**		**2.5**	**60-115**	**56**	**62.3**	**157**	**99.9998**	**15**
Teledyne EC-600	**Bipolar Alkaline**		**33.6**		**3.0**	**60-115**	**5.6**	**62.3**	**188**	**99.9998**	**15**
Teledyne EC-750	**Bipolar Alkaline**		**42**		**3.8**	**60-115**	**5.6**	**62.3**	**235**	**99.9998**	**15**
Teledyne HM-50	**Bipolar Alkaline**		**28**		**0.3**	**100**	**6.1**	**67.9**	**17**	**99.9998**	**15**
Teledyne HM-100	**Bipolar Alkaline**		**56**		**0.5**	**100**	**5.7**	**63.4**	**32**	**99.9998**	**15**
Teledyne HM-125	**Bipolar Alkaline**		**7**		**0.5**	**100**	**5.7**	**63.4**	**40**	**99.9998**	**15**
Teledyne HM-150	**Bipolar Alkaline**		**8.4**		**0.8**	**100**	**5.7**	**63.4**	**48**	**99.9998**	**15**
Teledyne HM-200	**Bipolar Alkaline**		**112**		**1.0**	**100**	**5.3**	**59.0**	**59**	**99.9998**	**15**