Carbon Emission Calculation and Benefit Analysis of Hydrogen Production Project by Electrolysis of Alkaline Water

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1 Background

1.1 Development status of hydrogen energy

With the continuous maturity of clean energy application technology and the continuous advancement of China’s energy structure adjustment, the development momentum of the hydrogen industry continues to be good, and was first written in “Government Work Report” in 2019. Hydrogen is recognized as a clean energy and is emerging as a low-carbon and zero-carbon energy. At present, the scale of hydrogen energy industry continues to expand, China has become the world’s largest hydrogen producer. China’s current capacity for hydrogen production is 25 million tons/year, and hydrogen production is 20-22 million tons/year, accounting for one third of the world’s hydrogen production, providing basic conditions for the early stage of industrialization of hydrogen energy development and its applications. In 2018, China’s renewable energy abandoned nearly 100 billion kWh, making it possible to achieve large-scale, low-cost and green production of hydrogen.

The main technical routes of hydrogen production in China are coal gasification and industrial by-product hydrogen. Biological hydrogen production and electrolytic water hydrogen production account for a relatively low proportion in the industry due to high cost. The combination of hydrogen energy technology and renewable energy technology is the main direction of future development. The production of hydrogen promotes the overall operation of the entire hydrogen energy industry chain through the effective combination of hydrogen production and renewable energy power, so as to achieve zero emissions in the use of hydrogen energy and effectively expand the secondary utilization of renewable energy.

The development of China’s hydrogen energy industry still faces many problems. In addition to the technical bottlenecks related to the production, transfer and utilization of hydrogen energy, it is also reflected in the following aspects:

1. Hydrogen production mainly relies on fossil fuels. From the perspective of the whole life cycle, the effect of carbon emission reduction is not obvious. Hydrogen produced from fossil fuels such as coal, natural gas, and petroleum accounts for 70% of the country’s total hydrogen production. Industrial by-products such as chlor-alkali chemicals account for
about 30% of hydrogen production.

2. The cost of hydrogen storage and transportation is too high. The hydrogen production sites in my country are far away from the central cities. Because the conditions for establishing long-distance hydrogen pipelines are not yet available, and the technology for mixing hydrogen in natural gas pipelines is not yet mature, the current domestic hydrogen transportation uses high-pressure trailers. Mainly, the weight of hydrogen carried by gas-hydrogen trailers only accounts for 1% to 2% of the total transportation weight, and the cost of storage and transportation per hundred kilometers is as high as 20 yuan/kg hydrogen.

3. The overall cost of hydrogen energy is too high. According to the current mainstream hydrogen production process in China, the cost of hydrogen production, storage and transportation and hydrogenation is considered comprehensively. The hydrogenation price for end users reaches 50-60 yuan/kg. Even if the renewable energy is considered to be 0.1 yuan/kwh, the cost is Will not reduce more. If a passenger car consumes 1kg of hydrogen per hundred kilometers and a diesel vehicle consumes 3kg of hydrogen per hundred kilometers, the cost of hydrogen has no advantage compared with fuel, and it is much more expensive than power battery cars.

Therefore, it is of great significance for promoting the application of hydrogen energy in cities to explore a method that can not only reduce carbon emissions throughout the life cycle, but also has good economy.

1.2 Potential advantages of hydrogen production in sewage treatment plants

Urban sewage contains a lot of energy, most of which exists in the form of biodegradable organic matter. At present, urban management departments consume energy to remove them and generate new carbon emissions. According to the statistics of the US EPA in 2006, the energy consumption of sewage treatment accounts for about 3% of the energy consumption of the United States, and nearly 50% of the electricity consumption is used for biological aeration. The energy contained in urban sewage is about 7-9 times the energy consumed for its treatment. In recent years, scientists have been committed to transforming urban sewage treatment plants into energy plants and resource plants and have achieved many results. Obtaining hydrogen energy from sewage is one of the potential directions of sewage energy. According to the basic principles of biofuel cells (MFCs), it is calculated theoretically that 1gCOD can convert 0.125g hydrogen, which shows that there are abundant hydrogen energy resources to be developed in urban sewage.

The basic principle of hydrogen production in sewage treatment is to disconnect the C chain or NH bond of pollutants in the sewage by electrochemical or biochemical methods. While obtaining gaseous H2, N2 and CH4, it also reduces the content of organic matter and
ammonia nitrogen in the water. This method couples the hydrogen production process with the sewage treatment process, and greatly reduces the sludge production of the sewage treatment plant. According to the understanding of the current technological progress, compared with the electricity consumption of water electrolysis for hydrogen production (>60kWh/kgH₂), the electricity consumption of sewage treatment for hydrogen production will be significantly reduced, and the reduction in sewage treatment and sludge disposal costs can be partially compensated for the energy cost of the hydrogen production process further reduces the overall cost of hydrogen production.

Urban sewage treatment plants are generally distributed around cities, and the distances to the city center and various commercial and residential clusters are relatively close. They can take advantage of their unique location advantages and establish independent hydrogen refueling stations, which can serve as heavy-duty trucks for inter-city transportation. It can also be integrated into the urban transportation system and serve the city’s commercial vehicles such as urban logistics vehicles, garbage trucks, muck trucks, sprinklers, and buses. The hydrogen can also be compressed or liquefied, and then distributed to urban communities for use in community distributed fuel cell power generation or heating. Hydrogen production in the sewage treatment plant reduces the cost and risk of hydrogen long-distance transportation, conforms to the concept of distributed hydrogen production and utilization, can reduce the overall cost of hydrogen energy use, and promotes the use of urban clean energy and carbon emission reduction.

In summary, the development of the hydrogen production capacity of urban sewage plants and the use of renewable energy to obtain hydrogen energy while processing sewage will help promote the transformation of sewage treatment plants into energy factories and resource factories, and promote the application of hydrogen energy in cities, which greatly reduces the carbon emissions of the whole society, has obvious cost advantages and certain economic benefits, and is a topic worthy of in-depth study.
2. Introduction to common hydrogen production processes

Organic matter (COD, BOD) in traditional wastewater is a kind of green energy. Some people have calculated the potential energy reserves in domestic sewage. The energy potential in sewage is 9–10 times higher than the energy consumed by sewage itself. In the process of sewage treatment, adding hydrogen production process can achieve the effect of water quality improvement and energy utilization. In the past few decades, the most mature development is hydrogen production from fossil fuels, which consumes a large number of non-renewable energy and emits greenhouse gas. Considering the current development status of China, the development of renewable energy hydrogen production process is the future trend. According to the technical category, mainly divided into pyrolysis gasification hydrogen, electrolytic water hydrogen, plasma hydrogen, semiconductor photocatalytic hydrogen, etc. The main way of large-scale industrial hydrogen production is pyrolysis and gasification. It is necessary to develop coupling hydrogen production in sewage plants, or use the “water” in sewage plants, or use the “pollution” in sewage. The common process for hydrogen production using “water” is electrolytic water. It is a new way to produce hydrogen by using “pollution” of wastewater treatment plant. There is a lack of relevant information. This section only introduces plasma hydrogen production.

2.1 Pyrolysis gasification hydrogen production

There are two main routes for producing hydrogen by cracking light hydrocarbons, propane dehydrogenation (PDH) and ethane cracking. Beginning in 2017, Chinese companies have started their efforts in the ethane-to-ethylene market, and many companies have successively announced that they will introduce low-cost light hydrocarbon feedstocks from the United States to produce ethylene. Propane dehydrogenation capacity is mainly concentrated in the eastern coastal areas of my country. The light hydrocarbon cracking hydrogen produces high purity, the lowest impurity content, and the purification difficulty is also small. However, due to raw materials, the cost is relatively high. According to incomplete statistics, by the end of 2022, domestic ethylene production capacity will reach 8.58 million tons and by-product hydrogen 553,400 tons (1 ton of ethylene by-product 64.5kg hydrogen), theoretically capable of supplying 2.2 million fuel cell vehicles. The process flow is shown in Figure 2.1.
2.2 Hydrogen production by electrolysis of water

As shown in Figure 2, hydrogen production from electrolyzed water is divided into acidic and alkaline components according to the electrolyte, and the principles are different.

(1) In alkaline and neutral media: the anode reaction is: \[ 2\text{OH}^- - 2e^- = \text{H}_2\text{O} + 1/2\text{O}_2\uparrow \]
    
    the cathode reaction is: \[ 2\text{H}_2\text{O} + 2e^- = 2\text{OH}^- + \text{H}_2\uparrow \]
    
    the total response is: \[ 2\text{H}_2\text{O} = 2\text{H}_2\uparrow + \text{O}_2\uparrow \]

(2) In acidic medium: the anode reaction is: \[ 2\text{H}_2\text{O} - 4e^- = 4\text{H}^+ + \text{O}_2\uparrow \]
    
    the cathode reaction is: \[ 4\text{H}^+ + 4e^- = 2\text{H}_2\uparrow \]
    
    the total response is: \[ 2\text{H}_2\text{O} = 2\text{H}_2\uparrow + \text{O}_2\uparrow \]

Figure 2.2 Schematic diagram of electrolyzed water under acidic (left) and alkaline (right) conditions

Hydrogen production by electrolysis of water can be divided into three main categories: alkaline water electrolysis (ALK), proton exchange membrane (PEM) electrolysis of water, and solid oxide (SOEC) electrolysis of water.

Hydrogen production by alkaline electrolysis of water uses 30% potassium hydroxide
solution or 25% sodium hydroxide solution as the electrolyte, and the working temperature is usually maintained at 70-90°C. Alkaline water hydrogen production electrolyzer is the core equipment of alkaline water electrolysis hydrogen production technology. The electrolytic cell is assembled by end pressure plates, gaskets, electrode plates, electrodes, permeable diaphragms and other parts.

The DC power supply supplies power to the alkaline water electrolyzer, and the electrolyte in the electrolyzer is decomposed to generate hydrogen and oxygen. The electrolyte containing oxygen enters the oxygen side separation and cooling device, the oxygen and the electrolyte are separated, and the electrolyte is returned to the alkaline water electrolysis tank. After the purity of the oxygen is tested, it is emptied or collected; the electrolyte containing hydrogen enters the hydrogen side for separation and cooling in the device, the hydrogen and the electrolyte are separated, and the electrolyte is returned to the alkaline water electrolyzer. After the purity of the hydrogen is tested, it is post-processed or collected.

2.3 Plasma hydrogen production

Liquid-phase plasma hydrogen production technology is a new hydrogen production technology. Since the liquid discharge used in the hydrogen production method generates plasma with high mass transfer efficiency, the hydrogen production effect is good, the hydrogen production is large, and the energy consumption of hydrogen production is low. Plasma hydrogen production method can produce hydrogen from various hydrogen-containing raw materials with a wide range of raw materials, which can avoid excessive dependence on non-renewable energy such as fossil fuels, and choose renewable energy such as ethanol and water. When other hydrocarbons are used as raw materials for hydrogen production, the plasma method can improve the flexibility and variability of the system, especially in vehicle hydrogen production.

Using plasma decomposition to produce hydrogen from the ionization of high-energy compounds in industrial wastewater, this technology not only converts pollutants in wastewater into valuable energy, but also reduces GHG emissions (carbon dioxide, carbon monoxide, hydrocarbons) by 30% to 60%, nitrogen oxide emissions can also be reduced by up to 60%. The use of high-energy compounds in wastewater to produce hydrogen can cut fuel production costs by half and significantly increase production. Plasma decomposition can create the sustainable “water-hydrogen-water cycle” required by the energy industry to achieve sustainable development, and represents an important key link for the successful introduction of storage and fuel cell technology.
3. Research content and framework

3.1 The goal and purpose of research

Based on the above background, the research objectives of this report are as follows:

The project plans to conduct systematic research on the technological development direction and R&D application stage of hydrogen production from sewage at home and abroad, and use a sewage treatment plant in Hunan as a research case to construct a life cycle list of sewage hydrogen production processes.

Taking the electrolysis of alkaline water as the research object, a complete life cycle assessment model is established to quantitatively evaluate the impact of the process on the environment during the construction and operation phases.

According to the results of the life cycle assessment, identify the key processes in the life cycle of the electrolytic alkaline water hydrogen production process, seek feasible methods to reduce environmental impact, and identify the key processes that generate costs in the process, and put forward effective suggestions for reducing costs, from environmental and economic perspectives. Two aspects of cost provide a scientific basis for optimizing the process of hydrogen production from sewage.

This study uses life cycle assessment methods and life cycle cost analysis to evaluate the carbon emissions and benefit analysis of the electrolytic alkaline water hydrogen production process during the life cycle. Through the above research, it is revealed that the use of renewable energy to combine sewage treatment with hydrogen production The economic and ecological value of the coupling process of the company is analyzed, and the policy bottlenecks that may be encountered in the development and promotion process are analyzed, and relevant suggestions are made.

3.2 Research content and technical route

Based on the background research of sewage treatment and traditional hydrogen production process, the electrolysis alkaline water hydrogen production is selected as the research object, and the carbon emissions and economic benefits of the process during the
life cycle are analyzed. The specific content is as follows:

3.2.1 **Determine research objectives and scope**

Through the investigation of the Hunan Sewage Treatment Plant and the process of hydrogen production by electrolysis of water at home and abroad, refer to relevant documents to determine the research objectives and system boundaries.

3.2.2 **Life cycle inventory analysis**

Through on-site inspections and reference to relevant documents, the inventory data of the hydrogen production process from electrolysis of water in the life cycle is determined. Secondly, determine the list price of materials and energy consumption for the process by inquiring on the Internet and contacting raw material suppliers.

3.2.3 **Life cycle impact assessment**

According to the life cycle inventory, modeling in the simpro software, the IPCC 2013 method is selected for analysis, and the carbon emissions during the life cycle of the electrolysis of alkaline water for hydrogen production are calculated. According to the analysis results, identify the main factors of the environmental impact of the process during the life cycle.

3.2.4 **Life cycle cost analysis**

The value of the environment and natural resources needs to be assessed in the decision-making process of environmental protection and economic operation. Life cycle cost analysis is used to measure and monetize the value of environment and natural resources. The results of life cycle cost analysis provide information support for the decision-making of the process in the life cycle.
3.3 Research of Carbon Emission Based on LCA Method

LCA is the compilation and evaluation of input, output and potential environmental impacts in the life cycle of a product or system. This LCA method is usually implemented by following the ISO 14040:2006 and 14044:2006 standards. LCA is considered to be the most powerful tool for assessing the environmental impact of any product, unit process or process system. Life cycle assessment (LCA) is a kind of environmental management technology, which takes into account the direct and indirect environmental load and environmental benefits generated by the stages and links of the whole life cycle of the evaluation object. LCA mainly focuses on the environmental impact of the evaluation object, and usually does not involve the social and economic factors of the evaluation object. However, life cycle assessment research can be combined with social and economic factors. For example, LCA can be combination with life cycle cost (LCC) and social life cycle assessment (SLCA).

3.3.1 System boundary

Determine the system boundary, that is, determine the unit process to be included in the system. We cannot trace all inputs and outputs of a process system and must define the boundaries of the system. By excluding some parts, i.e., ignoring them in the system, the results may be distorted. However, it is not necessary to quantify the input and output that have little impact on the overall research conclusions.

The system boundary of this study carries out the life cycle assessment of hydrogen production from electrolytic water from the construction stage and operation stage. In the
construction stage, the production and transportation of raw materials for photovoltaic panels and alkaline water electrolysis are mainly considered, and the traditional sewage treatment process is not considered. The reason is that the hydrogen production from electrolytic water does not have a great impact on the original process. The output of hydrogen production from alkaline water electrolysis in the operation stage is mainly hydrogen produced by electrolysis. Specific system boundaries are shown in Figure 2.5.

![Figure 2.5 System boundary](image)

**3.3.2 Functional unit**

One of the main purposes of functional units is to normalize the input and output data and provide benchmarks from a mathematical perspective. Therefore, functional units should be clearly defined and measured. In order to quantify the carbon emission during the whole life cycle of electrolysis alkaline water for hydrogen production, the functional unit is defined as the electrolysis water for hydrogen production system required to treat 1 m³ wastewater every day in the 25-year life cycle.

**3.3.3 Evaluation methods and software**

Based on the definition of research objectives, this study chose to analyze the Global Warming Potential (GWP) of the life cycle of electrolysis alkaline water for hydrogen production, because GWP is an environmental impact indicator used to quantify carbon emissions from products or processes.

The selection of quantitative evaluation method of carbon footprint meets the requirements of ISO14067: 2013, PAS2050: 2011, ISO14040: 2006, ISO14044: 2006, and considers the scientificity of the method, the availability of characteristic factors and the applicibility of the method. Table 2.1 shows the environmental impact and evaluation model.

**Table 2.1 Types of environmental impacts and evaluation models**
<table>
<thead>
<tr>
<th>Environmental impact type</th>
<th>Evaluation model</th>
<th>Contribution material</th>
<th>Influence type parameter</th>
<th>Method source</th>
<th>Impact type characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Global Warming Potential, GWP)</td>
<td>Berne Model-Global Warming Potential for 100 Years</td>
<td>CO₂, CH₄, CFC etc.</td>
<td>kg CO₂ eq.</td>
<td>IPCC, 2013</td>
<td>Types of global influence</td>
</tr>
</tbody>
</table>

Global Warming Potential (GWP): The method proposed by the IPCC Fifth Assessment Report (2013) to calculate the GWP value of the product life cycle. The IPCC (2013) method covers a variety of characteristic substances, including carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), carbon tetrafluoride (CF₄), hexafluoroethane (CF₆), sulfur hexafluoride (SF₆), hydrofluorocarbon (HFC) and halon, etc. This method is based on the relative radiative influence value of other greenhouse gases compared with carbon dioxide in a 100-year time frame, that is, the characterization factor, which is used to convert the emissions of other greenhouse gases into CO₂ equivalent (CO₂ eq.). For example, the impact of 1kg of methane on global warming in 100 years is equivalent to the impact of 28kg of carbon dioxide emissions on global warming, so based on the carbon dioxide equivalent (CO₂ eq.), the characteristic factor for methane is 28 kgCO₂ eq.

In the research, Simapro9 software was used to build the life cycle model of the process and calculate the carbon footprint results. Simapro is a professional LCA software developed by Pre Consultant, Dutch, which supports full life cycle process analysis. It has built-in Swiss Ecoinvent database, European Life Cycle Reference Database (ELCD), Agri-footprint, USLCL and other databases. In this study, data sets in the Ecoinvent, ELCD, USLCL, and Agri-footprint databases were used.

Ecoinvent database is developed by Swiss Life Cycle Research Center, including data from Western Europe, Switzerland, China and other regions. The database contains more than 10000 product and service data sets, involving chemical, energy, transportation, building materials, electronics, pulp and paper, waste treatment and agriculture.

### 3.3.4 Related assumptions

In the process of product or system life cycle assessment, in order to reduce the workload in the calculation process, reasonable assumptions can be made within the scope of the study, assumptions should be made clear explanation.

It is assumed that the process of hydrogen production from electrolytic alkaline water does not affect the original sewage treatment process, so the research content does not include the research on sewage treatment process.

At present, due to the lack of project research on hydrogen production from electrolytic
wastewater and the lack of relevant references, this report chooses electrolytic alkaline water as the research object.

3.3.5 Data selection principle

Based on the investigation and analysis of LCA research on various product processes at home and abroad, and referring to the requirements of trade-off criteria in the Product Environment Footprint (PEF) guidelines issued by the European Union in 2013, the basic trade-off principles areas follows:

1. Proportion based on inputs: the material energy input with the quality or energy input less than 2% is discarded, but the total proportion of the product input is not more than 5%. However, for substances with small quality but large life cycle environmental impact, they cannot be abandoned, such as gold and silver;

2. Proportion based on environmental impact: similar inputs are used to exclude raw materials with less actual impact. For any class of effects, if the same effect is less than 1% in the sum of a process/activity, the process can be discarded from the system boundary;

3. Ignore the means of production and infrastructure.

3.4 Life cycle cost analysis

3.4.1 Project cost analysis

Initial investment cost analysis

The sewage treatment plant of this project will build a photovoltaic system to obtain renewable energy hydrogen through the process of electrolyzing alkaline water to produce hydrogen. The project will set up a photovoltaic system, a sewage disposal co-production system and a mixed gas collection system.

The photovoltaic system of this project will be mainly set up above the pool and green land (not less than 6 meters). The photovoltaic module is installed in the form of steel structure and prestressed steel cable support, so the span is large. Compared with the traditional ground photovoltaic power station, it can fully improve the spatial utilization rate. Installation of photovoltaic modules specification, neat arrangement, good lighting permeability, does not affect the growth of vegetation. Avoid direct sunlight, reduce the growth of green algae, and reduce the cost of manual cleaning and mechanical washing.

The initial investment cost $S_i$ includes:

- (1) Equipment purchase fee $S_e$
- (2) Software and hardware purchase fees $S_m$
- (3) Construction engineering fee $S_c$
- (4) 25-year land cost $S_l$
- (5) Other costs (project management fees, survey and design fees, technical service fees) $S_o$

$S_i = S_e + S_m + S_c + S_l + S_o$
Initial cost total investment = total power × system cost per watt

**Operational cost analysis**

Operating costs include management costs, routine maintenance costs (refers to the total cost of daily maintenance of all buildings and equipment of photovoltaic panels), accidental maintenance costs. Due to the long life of photovoltaic panel equipment (≥ 25 years), the impact of inflation rate and social discount rate on the total cost should be considered when establishing the operation cost evaluation model. Assuming a (%) inflation rate, r (%) social discount rate and n (year) lifetime of photovoltaic systems.

\[
\text{Operating cost} = \text{total power} \times \text{system maintenance cost per watt}
\]

In the i year (i ≤ 25), the operating cost is

**3.4.2 Project income assessment**

The energy input in the operation stage is all from the photovoltaic system, so the energy input is 0, and the hydrogen produced by electrolysis is sold.

Without considering the financial subsidies of the central and local governments, the calculation formula of the photovoltaic system power generation in the first year is as follows: the photovoltaic system power generation in the first year = the total power of the photovoltaic system × the average peak sunshine hours × 365 days × the energy efficiency factor of the photovoltaic system. Unit power generation within 25 years of life cycle can be calculated and total hydrogen production can be obtained.

Project revenue \( B_i \) = total amount of hydrogen produced × selling price per ton of hydrogen

When the project income is greater than the total cost of the project input, the project can be considered to start to reap rewards.

Return on investment ROI =

**3.4.3 Project cost-benefit analysis**

**Present value calculation**

The present value of the benefits or costs obtained in the nth year in the future is determined by the following formula:

\[
\text{In formula}: \\
\text{ present value of benefits}; \\
\text{ present value of cost}; \\
\text{ Benefits and expenses incurred in the nth year}; \\
\text{ r } : \text{ social discount rate}; \\
\text{ n } : \text{ calculation period, year.}
\]

**Economic Net Present Value (ENPV)**

Economic net present value (ENPV) is an absolute indicator reflecting the net contribution of projects to the national economy. Items with economic net present value
greater than zero or equal to zero can be considered.

In formula:
- : the total benefit and total cost incurred in the i-th year;
- r : social discount rate;
- n : calculation period, year.

4. Collection and Analysis of Life Cycle List of Hydrogen Production by Electrolysis of Alkaline Water

Listing analysis includes data collection and calculation to quantify input and output in the product system. Inventory analysis is based on the data of resources, energy consumption and pollutant emissions throughout the life cycle, and it is an objective quantitative process impact assessment of the evaluation object. In the implementation of LCA, the most difficult task is to collect data. Although there are large amounts of available data in the database, some data may not be applicable due to geographical problems. The inventory data of this report are mainly collected and analyzed from the construction stage and the operation stage. The data are from field research and literature reference.

4.1 Data processing

The collection of inventory data is based on the functional unit, that is, the electrolysis water hydrogen production system needed to treat 1 m³ wastewater every day in the 25-year life cycle. According to the daily sewage treatment amount, the life of photovoltaic panels and electrolysers is counted to obtain the data of the construction stage in the 25-year life cycle.

According to the industrialization data provided by Suzhou Jingli Institute, the electrolysis alkaline water hydrogen production system electrolyzes 1m³ of pure water, assuming an energy conversion rate of 60%, and a power consumption of 6666.7 kWh. In the end, 111 kg of hydrogen can be produced. Treating 1m³ of sewage per day, operating for 25 years, the total hydrogen production is 1013.9 tons of hydrogen, and the power consumption is 6.08×107 kWh.

The grid power generation Ep of the photovoltaic system is calculated as follows:

\[ E_p = H \times P \times K_1 \]

- P —— is install capacity for the system (kWp)
- H —— is the local standard hours of sunshine
- K1 —— is the overall efficiency of the system

The average annual sunshine time under standard illumination in Hunan area is 3.1-3.8h. This report takes 3.29h. The overall efficiency of the system is a correction coefficient after considering various factors. The general value is 75%-85%. The overall efficiency is 80%. Then the system installation capacity P:
P=E[H]K
The calculated system installation capacity is 2532kWp.

Since the normal service life of the photovoltaic system is 25 years, it does not need to be replaced during the life cycle. The service life of the electrolysis water hydrogen production equipment is 15 years, so the statistical inventory data during the life cycle is the materials and energy consumption required for the production of 1.67 groups of equipment.

4.2 List collection and analysis during the construction phase

The collection of inventory data is based on the functional unit, that is, the electrolysis water hydrogen production system needed to treat 1 m³ wastewater every day in the 25-year life cycle. According to the daily sewage treatment amount, the life of photovoltaic panels and electrolyzers is counted to obtain the data of the construction stage in the 25-year life cycle.

4.2.1 PV panel production stage data

The production of photovoltaic systems mainly includes the production of cells and battery modules.

The cell production process mainly includes: texturing, cleaning before diffusion, phosphorus diffusion, PSG removal, edge etching, coating, screen printing, burning, testing and grading. The texturing process mainly uses nitric acid and hydrofluoric acid to corrode the silicon wafer, and then undergoes a pickling process to remove water, metal ions and other magazines on the surface of the silicon wafer. Then, a p-n junction is formed through a diffusion process, and hydrofluoric acid is used to remove the phosphorous silicate glass on the surface. Next, Si H4 and NH3 are used to generate plasma under the action of high-frequency glow discharge. The plasma is adsorbed on the surface of the silicon wafer and reacts to form a silicon nitride film on the surface of the silicon wafer. Finally, it is printed and burned to form a cell. The cell data comes from the Ecoinvent database.

The manufacturing of crystalline silicon solar cell modules mainly uses materials such as tempered glass and EVA to monolithically interconnect and encapsulate crystalline silicon solar cells to protect electrode contact, prevent interconnection lines from corrosion, and avoid cell chipping. Packaging quality directly affects the service life of crystalline silicon solar cell modules. The list data of photovoltaic modules in production are shown in Table 2.2

| Table 2.2 List of photovoltaic module production process |
|------------|---------|---------|-------------|-------------|
| name       | material| data    | mode of transport | transport distance |
| cell       | cell    | 15923m³ | truck        | 100Km        |
| copper     | copper  | 1.24 t  | truck        | 20Km         |
| fresh water| water   | 882680 t| truck        | 21Km         |
| EVA film | EVA | 17.88 t | truck | 13Km |
| TPT backplane | Polyvinyl fluoride | 9.22 t | truck | 17Km |
| Tempered glass | glass | 157.5 t | truck | 15Km |
| Organic silica gel | Silica gel | 101.28 t | truck | 56Km |
| Aluminum frame | aluminum | 33.22 t | truck | 10Km |
| production energy consumption | electricity | 148122 kWh | / | / |

4.2.2 Production stage data of electrolysis equipment

The material list of electrolysis equipment that processes 1m³ sewage every day and has been in operation for 25 years is shown in Table 2.3. Alkaline water hydrogen production electrolyzers have various internal structures, which can be basically divided into oxygen electrolysis, hydrogen electrode, electrolyte, connection part and frame. The data source refers to the research and analysis of Guangling Zhao et al. on electrolyzed water technology. The hydrogen electrode, oxygen electrode and connecting parts in the traditional electrolysis tank are all made of the same material. Choosing a nickel plate with a higher density can meet the requirements of the above three components. The oxygen electrode is usually nickel, so a simple nickel plate or a nickel-plated steel plate with an open geometry is usually used. This report selects porous solid nickel plates. Hydrogen electrodes are usually made of different kinds of active nickel plates. In this study, we select nickel plates with nickel sulfide coating on the surface. Nickel plates and diaphragms (porous separators between the electrodes, formerly asbestos) are then alternately stacked in a suitable frame to ensure that there is a large space between the water electrolyte and the gas. The membrane is reinforced by a polyphenylene sulfide (PPS) mesh, with a total porosity of approximately 50%. The diaphragm can be prepared by the reverse phase immersion precipitation method. The electrolyte is 30% potassium hydroxide solution, and the frame is made of stainless steel. Electricity is the main energy used in the equipment assembly process.

<p>| Table 2.3 List of production process data of electrolysis equipment |
| name | material | data | mode of transport | transport distance |
| oxygen electrode | nickel plate | 39.2Kg | truck | 85Km |
| hydrogen electrode | nickel plate | 39.2Kg | truck | 85Km |
| | nickel sulfide coating | 1.4Kg | truck | 30Km |
| electrolyte | 30% potassium hydroxide | 20.8Kg | truck | 15Km |
| connection material | nickel plate | 170.3Kg | truck | 85Km |
| frame | polyphenylene sulfide | 70.79Kg | truck | 15Km |</p>
<table>
<thead>
<tr>
<th>production energy consumption</th>
<th>stainless steel</th>
<th>84.8Kg</th>
<th>truck</th>
<th>10Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>electricity</td>
<td>50.3kWh</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

### 4.3 List collection and analysis during operation phase

The energy input in the operation phase is all from the photovoltaic system, so the energy input is zero, and all the hydrogen produced by electrolysis is sold. Assuming that all hydrogen is burned to generate electricity, under normal temperature and pressure conditions, the combustion value of hydrogen is $1.43 \times 10^8$J/kg, and the heat released by the combustion of 1kg of hydrogen is equivalent to 39.7 kWh of electricity. 1013.9t of hydrogen can indirectly reduce the production of $4.0 \times 10^7$ kWh of electricity.

### 5. Calculation of Carbon Emissions in the Life Cycle of Electrolyzed Water Hydrogen Production

#### 5.1 Carbon emissions during the construction phase

The carbon dioxide emissions during the construction phase are $4.34 \times 10^6$ kg CO₂ eq. The carbon dioxide emissions of photovoltaic modules accounted for 99.9% of the entire construction phase.

#### 5.1.1 Carbon emissions during the production phase of photovoltaic modules

The carbon emission during the photovoltaic module production stage is $4.34 \times 10^6$ kg CO₂ eq. The CO₂ emissions from the production of polycrystalline silicon cells are $2.76 \times 10^6$ kg CO₂ eq, accounting for 63.6% of the production stage, and are the main source of CO₂ emissions. The production process of photovoltaic modules consumes a lot of water resources. The carbon emission during the production of clean water is $4.97 \times 10^5$ kg CO₂ eq, which accounts for 15.5% of this stage. Followed by the production of silica gel and tempered glass, accounting for 7.75% and 6.67% respectively. The carbon emissions during the production phase of photovoltaic modules are shown in Figure 2.6.
Figure 2.6 Carbon emissions during the production phase of photovoltaic modules

5.1.2 Carbon emissions during the production phase of electrolysis equipment

The carbon emission during the production stage of the electrolysis equipment is 3.47×103 kg CO₂ eq. The most used material in the production process of electrolyzers is nickel plate, which is also the main source of carbon emissions in the production process. The connection material used 170 kg of nickel plates, which produced 1.86×103 kg CO₂ eq, which accounted for 53.5% of the carbon emissions at this stage. The carbon emissions of polyphenylene sulfide and stainless steel accounted for 14.4% and 5.73%, respectively. Carbon emissions from nickel sulfide and energy consumption during assembly are negligible. Figure 2.7 shows the results of carbon emissions during the production stage of electrolysis equipment.

Figure 2.7 Carbon emissions during the production stage of electrolysis equipment

5.2 Carbon emissions during operation

Carbon emissions during the operation phase -4.28×10⁷ kg CO₂ eq. The hydrogen produced can indirectly reduce the production of electricity from the national grid, thereby reducing carbon dioxide emissions.
5.3 Overall life cycle assessment of construction and operation

The carbon emissions of hydrogen production from electrolysis of water during the 25-year life cycle are $-3.84 \times 10^7$ kg CO₂ eq. The environmental benefit generated during the operation phase is about 10 times that of the construction phase.

Figure 2.8 25-year life cycle of hydrogen production from electrolysis of water

6. Collection and analysis of life cycle economic inventory

6.1 Project cost

6.1.1 Initial investment cost

1. Photovoltaic system

According to our survey results, in 2020, the cost of ordinary ground photovoltaic power plants has been greatly reduced, about 3.35 yuan/Wp; such as this project’s high-altitude suspension cable structure, its cost is only 4-4.5 yuan/Wp, This project costs 4 yuan/Wp.

The installed capacity of the photovoltaic system of this project is 2743kWp, then:

Initial investment cost of the project

= PV system installed capacity × unit cost

= 2743 kWp × 4 yuan/Wp × 1000 = 10.97 million yuan

among them:

(1) Equipment purchase cost S_e accounts for about 60% of the total investment, which is about 6.58 million yuan.

(2) Software and hardware purchase cost S_in accounts for about 5% of the total investment, about 550,000 yuan.
(3) The construction cost Sc accounts for about 20% of the total investment, which is about 2.19 million yuan.

(4) 25-year land cost Sl accounts for about 10% of the total investment, about 1.1 million yuan.

(5) Other costs (project management fees, survey and design fees, technical service fees) So accounted for about 5% of the total investment, about 550,000 yuan.

![Pie Chart](image)

**Figure 2.9 The composition and details of initial investment costs (ten thousand yuan)**

2. Hydrogen production system

This project selects an alkaline water electrolysis hydrogen production equipment with a rated hydrogen output of 1000/h. The cost of the equipment to synthesize a unit cubic meter of hydrogen is 13 yuan/kg. This project treats 1m³ of sewage every day. After 25 years of operation, the total hydrogen production is 1013.9 tons of hydrogen, which is about 1013900 kg of hydrogen.

Initial investment cost of the project

\[
= \text{Total hydrogen production} \times \text{unit cost} \\
= 1013900 \text{kg} \times 13 \text{ yuan/kg} = 13.18 \text{ million yuan}
\]

Therefore, the initial total investment cost of this project is: 10.97 million yuan + 13.18 million yuan = 24.15 million yuan.

**6.1.2 Operating cost**

1. Photovoltaic system

According to the survey, in 2020, it is reasonable to take 4 cents/Wp per year for the maintenance fee of the photovoltaic system. Therefore, the operating costs for the first year
are:

\[ S_1 = \text{total power} \times \text{system maintenance cost per watt} \]
\[ = 2743 \text{ kWp} \times 4 \text{ minutes/Wp} \times 1000 = 110,000 \text{ yuan/year} \]

2. Electrolysis hydrogen production system

The maintenance cost of hydrogen production by alkaline electrolysis is about 3.15 yuan/kg per year, and the annual hydrogen production is 40556kg. Therefore, the operating cost for the first year is:

\[ S_1 = \text{Annual hydrogen production} \times \text{system maintenance cost per kg} \]
\[ = 40556 \text{ kg} \times 6 \text{ yuan/kg} = 128,000 \text{ yuan/year} \]

Due to the long life of photovoltaic panels and hydrogen production equipment (≥25 years), the impact of inflation rate and social discount rate on the total cost should be considered when establishing an operating cost evaluation model. According to the "Construction Project Economic Evaluation Methods and Parameters (3rd Edition)" issued by the National Development and Reform Commission, the social discount rate \( r \) is 8%, the inflation rate \( \alpha \) is 4%, and the life of photovoltaic panel equipment is 25.

In the i year (\( i \leq 25 \)), the operating cost is

### 6.1.3 Project life cycle cost estimation

The 25-year life cycle cost of this project is estimated as follows:

**Table 2.4 25-year life cycle cost schedule of the project**

<table>
<thead>
<tr>
<th>Years</th>
<th>Initial investment cost of the project (ten thousand yuan)</th>
<th>Operating expenses (ten thousand yuan)</th>
<th>Total cost (ten thousand yuan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2,415.00</td>
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<td>2,415.00</td>
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<td>22.88</td>
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<tr>
<td>3</td>
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<td>22.00</td>
</tr>
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<td>21.16</td>
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<tr>
<td></td>
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<td>16.08</td>
<td>16.08</td>
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<tr>
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<td>-------</td>
</tr>
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<tr>
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<td>10.86</td>
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<td>-</td>
<td>9.66</td>
<td>9.66</td>
</tr>
<tr>
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<td>-</td>
<td>9.28</td>
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<tr>
<td>25</td>
<td>-</td>
<td>386.68</td>
<td>2,801.68</td>
</tr>
</tbody>
</table>

As shown in the table, the total 25-year life cycle cost of the photovoltaic system of this project is approximately 28.02 million yuan.

### 6.2 Project income

The energy input in the operation phase is all from the photovoltaic system, so the energy input is zero, and all the hydrogen produced by electrolysis is sold. The total hydrogen production of this project in 25 years is 1013.9 tons. Currently, the unsubsidized price of hydrogen in the market averages 65 yuan per kilogram.

Project revenue \( B_i = \text{total hydrogen production} \times \text{hydrogen price per ton} = 1013900 \text{ kg} \times 65 \text{ yuan/kg} = 65.9 \text{ million yuan.} \) When the project income is greater than the total cost of the project input, the project can be considered to start to reap rewards.
Figure 2.10 Annual cumulative total cost and total revenue of the project (ten thousand yuan)

As shown in Figure 2.10, in the 10th year, the project is expected to accumulate total income of 26.36 million yuan. In the same year, the cumulative total cost of the project is approximately 26.16 million yuan. It can be considered that the project began to receive returns in that year.

Return on investment ROI =

= The rate of return on investment of this project is 2.35%.

6.3 Cost-benefit evaluation

According to the calculation formula of economic net present value (ENPV), the annual ENPV value can be calculated, as shown in the following table.

Table 2.5 Annual ENPV calculation results

<table>
<thead>
<tr>
<th>Years</th>
<th>Total cost (ten thousand yuan)</th>
<th>Total income (ten thousand yuan)</th>
<th>TB-TC (ten thousand yuan)</th>
<th>ENPV</th>
</tr>
</thead>
<tbody>
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<td>0</td>
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<td>-2,415.00</td>
<td>-2,415.00</td>
</tr>
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<td>263.60</td>
<td>253.94</td>
<td>40.05</td>
</tr>
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<td>9.28</td>
<td>263.60</td>
<td>254.32</td>
<td>37.13</td>
</tr>
<tr>
<td>总计</td>
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<td>6,590.00</td>
<td>3,788.32</td>
<td><strong>208.97</strong></td>
</tr>
</tbody>
</table>

The economic net present value of this project is 209, and the net present value is greater than zero. Therefore, it is considered that the project has a large net contribution to the national economy during its life cycle and is a project that can be considered.

**7. Conclusion**

This paper aims to study the carbon emissions and cost analysis of the electrolysis alkaline water hydrogen production system during the 25-year life cycle. Through the inventory analysis, SimaPro9 software and the IPCC 2013 impact assessment method are used to simulate the electrolysis alkaline water hydrogen production system. Through case analysis and research, the life cycle assessment of the 25-year life cycle of the electrolysis
alkaline water hydrogen production system is carried out in two aspects: the construction phase and the operation phase. The conclusions are as follows:

1. In terms of overall environmental impact, the carbon emissions of hydrogen production from electrolysis of water during the 25-year life cycle are $-3.84 \times 10^7$ kg CO2 eq. The operation stage has the greatest impact on the environment, indirectly reducing the emissions of $4.28 \times 10^7$ kg CO2 eq.

2. The hydrogen production system by electrolysis of alkaline water will only produce carbon emissions during the construction phase. The source of carbon emissions is mainly the production of polysilicon batteries, which account for 63% of the carbon emissions during the construction phase. In order to improve the environmental benefits of the system, the production process of polycrystalline silicon cells can be improved to reduce carbon emissions during the production process.

3. The estimated total investment of this project is 28.02 million yuan, including initial system construction and equipment investment costs totaling 24.15 million yuan and 25-year operating costs totaling 3.87 million yuan. The total hydrogen production of the project in 25 years is 1013.9 tons. The hydrogen will be sold directly. The total income of the project in 25 years is 65.9 million yuan. Through calculation and analysis, this project will achieve a return in the tenth year, with a return on investment of 2.35%. In order to evaluate the environmental and economic benefits of the project, the economic net present value is used for evaluation. The economic net present value of the project is 209, which is greater than zero. Therefore, it is considered that the project has a large net contribution to the national economy during its life cycle and is an investment project that can be considered.