Статья поступила в редакцию 04.08.17. Ред. рег. № 2608 The article has entered in publishing office 04.08.17. Ed. reg. No. 2608

УДК 661.961.

MODELING AND SIMULATION OF THE PRODUCTION OF HYDROGEN USING HYDROELECTRICITY IN VENEZUELA*

Alfonso Contreras[a]**, *, *Fausto Posso***[b]**, *T. Nejat Veziroglu***[c]

[a]Department of Chemistry Applied to Engineering
UNED, 28040, Madrid, Spain
tel.: +3491 398 64 96; fax: +3491 398 60 43; e-mail: acontreras@ind.uned.es,
[b]Science Department, ULA-Táchira, Sede Paramillo, 5001, San Cristybal, Venezuela
e-mail: fausto@ula.ve
[c]Clean Energy Research Institute, Mechanical Engineering, University of Miami
P.O. Box 248294 Coral Cables, FL 33124-0620, USA
tel.: +1 305 284 46 66, fax: +1 305 284 47 92

doi: 10.15518/isjaee.2018.22-24.088-095

Referred 18 August 2017 Received in revised form 31 August 2017 Accepted 12 September 2017

The purpose of this work is to develop and evaluate a mathematical model for the process of hydrogen production in Venezuela, via electrolysis and using hydroelectricity, with a view to using it as an energy vector in rural sectors of the country. Regression models were prepared to estimate the fluctuation of the main variables involved in the process: the production of hydrogen, the efficiency of energy conversion, the cost of hydroelectricity and the cost of the electrolyser. Finally, the proposed model was applied to various different time-horizons and populations, obtaining the cost of hydrogen production in each case. The results obtained are well below those mentioned in the references, owing largely to the low cost of the electricity used, which accounts for around 45% of the total cost of the system.

Keywords: hydrogen production; electrolysis; hydroelectricity; Venezuela.

МОДЕЛИРОВАНИЕ ПРОЦЕССА ПРОИЗВОДСТВА ВОДОРОДА С ИСПОЛЬЗОВАНИЕМ ГИДРОЭЛЕКТРИЧЕСТВА В ВЕНЕСУЭЛЕ

А. Контрерас[1]****, Ф. Поссо***[2]***, Т.Н. Везироглу***[3]

[1]Национальный университет дистанционного обучения (), Кафедра технической химии
UNED, Мадрид, 28040, Испания
тел.: +3491 398-64-96; факс: +3491 398-60-43; e-mail: acontreras@ind.uned.es,
[2]Университет Анд
Сан-Кристобаль, Парамилло, штат Тачира, 5001, Венесуэла
e-mail: fausto@ula.ve
[2]Институт чистой энергии, Университет Майами, США
а/я 248294, Coral Cables, Флорида 33124, США
тел.: +1(305)284-46-66; факс: +1(305)284-47-92

doi: 10.15518/isjaee.2018.22-24.088-095

Заключение совета рецензентов: 18.08.17 Заключение совета экспертов: 31.08.17 Принято к публикации: 12.09.17

Целью этой работы является разработка и оценка математической модели процесса производства водорода в Венесуэле путем электролиза и с использованием гидроэлектричества, для того чтобы с помощью

---

[*] *Contreras A., Posso F., Veziroglu T.N.* Modeling and Simulation of The Production of Hydrogen Using Hydroelectricity in Venezuela // Международный научный журнал «Альтернативная энергетика и экология» (ISJAEE), 2018;22-24:88-95.
2006 International Association for Hydrogen Energy. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijhydene.2006.10.054

водорода передавать энергию в сельские районы страны. Были подготовлены регрессионные модели для оценки флуктуации основных переменных, участвующих в процессе: получение водорода, эффективность преобразования энергии, стоимость гидроэлектричества и стоимость электролизера. Наконец, предлагаемая модель была применена к разным временным горизонтам и генеральной совокупности, при этом были определены затраты на производство водорода в каждом случае. Полученные значения оказались значительно ниже упомянутых в других работах, в основном в связи с низкой стоимостью используемой электроэнергии, на которую приходится около 45 % общей стоимости системы.

Ключевые слова: производство водорода; электролиз; гидроэлектростанция; Венесуэла.

T.N. Veziroglu
Турхан Н. Везироглу

Information about the author: Ph.D. in Heat Transfer, Professor, President of International Association for Hydrogen Energy, a member of 18 scientific organizations.

Education: the City and Guilds College, the Imperial College of Science and Technology, University of London with degrees in Mechanical Engineering, 1946, advanced studies in engineering, 1947; Ph.D. in Heat Transfer, 1951.

Awards: recipient of several international awards.

Experience: University of Miami, Engineering faculty, Department Chairman, Professor, 1962–1979; Clean Energy Research Institute, Coral Gables, Fl, Director, 1974–2009; International Centre for Hydrogen Energy Technologies, Istanbul, Turkey, Founding Director, 2004–2007. University of Miami, Professor Emeritus, 2009–present. International Association for Hydrogen Energy, Founding President, 1976–present. Honorary Editor-in-Chief of the International Scientific Journal for Alternative Energy and Ecology (ISJAEE).

Research interests: two-phase flow instabilities; interstitial heat transfer; solar energy; global warming; environmental problems; renewable energy sources and hydrogen energy system.

Publications: more than 350, editor of 160 books and proceedings, co-author of the book "Solar Hydrogen Energy: the Power to Save the Earth".

Сведения об авторе: д-р наук (теплообмен), профессор, президент Международной ассоциации водородной энергетики, член 18 научных организаций.

Образование: Городской профессиональный колледж, Имперский колледж науки и техники (Великобритания), Лондонский университет по специальности «машиностроение» (1946 г.); доктор наук по теплообмену (1951 г.).

Награды: лауреат нескольких международных наград.

Опыт работы: профессор, заведующий кафедрой технического факультета в университете Майами (1962–1979 гг.); директор Института чистой энергии (США), Coral Gables, Флорида (1974–2009 гг.); основатель и директор Международного центра технологий по водородной энергетике, Стамбул, Турция (2004–2007 гг.). почетный профессор университета Майами (2009 – по настоящее время); основатель и президент Международной ассоциации водородной энергетики (1976 – по настоящее время). Почетный главный редактор Международного научного журнала «Альтернативная энергетика и экология» (ISJAEE).

Область научных интересов: неустойчивость двухфазного потока; внутренняя теплопередача; солнечная энергия; глобальное потепление; экологические проблемы; возобновляемые источники энергии и система использования водородной энергии.

Публикации: более 350, редактор 160 книг и трудов конференций, соавтор книги «Солнечная водородная энергетика: сила, которая сохранит Землю».

1. Introduction

Due to its exceptional properties and versatility, hydrogen is an increasingly strong option for replacing fossil fuels in the long-term [1]. A large number of feasibility studies have been carried out, based on simulation models for the introduction of hydrogen into the energy systems of Europe and Asia [2–5].

In Latin America, R&D programmes on hydrogen energy are scarce, with Brazil the leader in research on H_2 energy production from renewable sources, in particular hydroelectricity [6–8]. Venezuela itself has been, historically, a large-scale producer and exporter of fossil fuels, to the extent that its economy is determined by the behaviour of oil on the world market. In terms of home consumption, fossil sources and hydropower are the leading suppliers, and in per capita consumption it is the first among the five largest Latin American countries [9], mainly induced by the low consumer prices. However, there is a large sector of the rural population that has no permanent energy supply whatsoever, as it is both difficult and costly to supply them from the traditional energy system. The Venezuelan State has proposed using the country's large potential for alternative energies for this purpose, but has not included hydrogen among the options [10]. In this context, it is particularly important to develop a solar-hydrogen energy system in Venezuela. The introduction of such a system would enable these isolated and underprivileged rural areas to gain autonomy in terms of energy, improving quality of life and stimulating the local economy because it is labour-intensive, and promoting sustainable development.

Bearing all this in mind, the purpose of our study was to carry out a feasibility study based on the modeling and simulation of the production of hydrogen from hydroelectricity in Venezuela, and for the uses described above. In order to do so, mathematical structures were devised that model the behavior of hydrogen production, the efficiency of energy conversion, the cost of electricity and the cost of electrolyser, on the basis of historical data, bibliographical references and information provided by manufacturers. The simulation was made according to various different operating conditions, and for a 20-year time horizon, as from the year 2000.

As a basis for energy comparison, we have chosen the higher heating value (HHV) of hydrogen.

Nomenclature	
boe	barrels of oil equivalent
C_{EE}	annual electricity cost, \$ year^{-1}
C_{EL}	unit cost of electrolysis plant, \$ kW^{-1}
C_{HE}	annual consumption of hydrogen per inhabitant, N m^3 H$_2$ year^{-1} inhab.$^{-1}$
C_I	annual cost of consumption, \$ year^{-1}
C_{INV}	annual investment cost, \$ year^{-1}
C_{OM}	annual cost of operation and maintenance, \$ year^{-1}
C_T	total electricity consumption, kWh N m^3 H_2^{-1}
C_{TP}	total annual cost of production of hydrogen, \$ year^{-1}
E_A	electricity consumption: auxiliary equipment, kWh N m^3 H_2^{-1}
E_C	electricity consumption: compression, kWh N m^3 H_2^{-1}
E_E	electrolyser efficiency, kWh N m^3 H_2^{-1}
N_H	number of inhabitants, inhab.
P	electrical power of electrolysis plant, MW
P_H	annual production of hydrogen, N m^3 H$_2$ year^{-1}
t	time, years
T_{EI}	industrial electricity tariff, \$ kWh^{-1}
Model parameters	
d	annual discount rate (%) = 10
DI	annual availability, h year^{-1} = 8328
F_M	handling factor = 1.1
k_0	constant Eq. (2), kWh N m^3 H_2^{-1} = 9.0160×10^{32}
k_1	constant Eq. (2), kWhNm^3 H_2^{-1} = 3.5100
T	constant Eq. (2), year = 26.2417
n	lifespan, years = 20
OM	rate for O&M (%) = 5
HHV	higher heating value of hydrogen =12.8 MJ / Nm^3
F	capital recovery factor = 0.1175

2. The Venezuelan energy system

Due to the proposed end-uses of the hydrogen produced, we shall first describe the main aspects of Venezuela's current energy system, in particular as regards residential, urban and rural consumption.

2.1. Primary energy production and reserves

The Venezuelan energy system has been, and remains, governed by fossil fuels. The high rate of production of oil and its derivatives has placed Venezuela among the top ten oilproducing countries in the world. This position is the result of the high volume of proven oil reserves, the duration of which, at the 2002 production rate, has conferred upon Venezuela a privileged world status (Table 1).

Table 1

Primary energy production and reserves in Venezuela

Таблица 1

Добыча и запасы источников первичной энергии в Венесуэле

Source	Production (Mboe)	%	Reserves	Ratio R/P (years)
Oil	1106	72.3	78 Bboe	75
Natural gas	247	16.2	4.19 Tm^3	111
Hydropower	134	8.7	—	—
Coal	43	2.8	1309 Mtm	188

Source: Ref. [11]. Year 2002.

2.2. Potential for alternative energies

Official studies indicate there is great potential (Table 2), equivalent to around three times Venezuela's average oil production rate for the year 2002, which shows the great possibilities of this kind of energy.

Table 2

Potential for alternative energies in Venezuela

Таблица 2

Потенциал альтернативных источников энергии в Венесуэле

Type of energy	**Potential (Mboe)**
Mini-hydro	47.5
Bioenergy	124.1
Solar (15% conversion)	1664.4
Eolic (3% conversion)	514.7
Geothermic	54.8
Other alternative energies	193.5
Partial potential	2598.8
Large-scale hydropower	678.9
Total potential	**3277.9**

Source: Ref. [12]. Year 2002.

2.3. Final residential consumption

Final residential consumption saw an average tendency to rise in the period between 1970–2002 (Fig. 1, continuous line), and in the latter year it represented 11% of total consumption [11]. In terms of the pattern for residential consumption, electricity supply, liquified petroleum gas (LPG) and natural gas made up over 95% of the whole. Gas was mainly used for cooking, as almost 93% of homes use LPG for this purpose [13]. As for electricity, the population supplied by the electrical power system for the year 2004 was 96% of the national total [14].

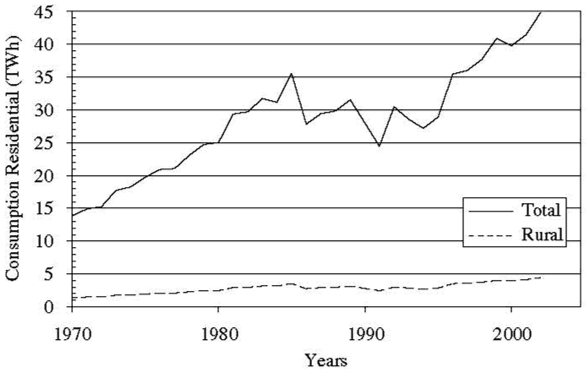

Fig. 1 – Consumption of residential energy. Period 1970–2002
Рис. 1 – Потребление энергии жилищным сектором (1970–2002 гг.)

If we look at the rural population, its contribution to residential consumption averaged 10% during the same period (Fig. 1, discontinuous line), and the energy consumption per rural inhabitant has been estimated at 191 kWh/year, which is equivalent to 11% of the urban sector. Also, the percentage of the rural population with no kind of permanent energy supply is 27%—828,000 inhabitants—and there is no plan to satisfy this need using the traditional energy system [10].

3. Energy model

This consists of formulating equations on the variation of hydrogen production and the associated consumption of electricity, including the hydrogen purification and compression stages. The hydrogen that is produced will go to satisfy the energy requirements in sectors of the rural population.

3.1. Annual hydrogen production

The annual production of H_2 will be considered directly proportional to the residential energy consumption per rural inhabitant, expressed as equivalent hydrogen (C_{HE}), and to the number of inhabitants to be supplied with energy (N_{H}), according to a handling factor (F_{M})

$$P_{\mathrm{H}} = F_{\mathrm{M}} C_{\mathrm{HE}} N_{\mathrm{H}}. \qquad (1)$$

The heightened level of migration from rural to urban areas in the period between 1950–2001 and the deterioration of socio-economic conditions of the rural population over the last 20 years, have caused their per capita energy consumption to remain almost unchanged [13]. In this context, a constant value for C_{HE} was assumed for time horizon of the simulation.

3.2. Electrical power required for the production and compression of the hydrogen

The electrical power for obtaining and subsequently treating the hydrogen can be supplied by various primary sources. In this case we used hydropower, in order to make good use of Venezuela's competitive advantages in terms of its great hydropower potential and low electricity costs. As regards the first point, it should be mentioned that hydroelectric power comprises 22% of the total power supplied by alternative energy in Venezuela, and only 19% of this amount is used (Tables 1 and 2). Even if, hypothetically, the hydrogen was used to satisfy the energy requirements of the rural population who currently have no energy supply, the electricity required would be less than 1% of usable power. These figures confirm that hydroelectricity is viable as a primary source for hydrogen production in Venezuela. As for cost, because no official data is available on the real cost of producing hydroelectricity in Venezuela, for our financial study we used the prices paid by consumers for electricity in that country, which are among the lowest in South America [15].

3.2.1. Electrolyser

The electrical consumption of the electrolyser is considered to be the factor most likely to require technological improvement and, at this time, active research it being made into improving the design parameters related to the voltage and size of the electrolytic cell, the current density and the temperature of the process, amongst others. The consumption of electricity per volume unit of hydrogen produced, has been called energy efficiency, or E_E. The information used for constructing a mathematical model to represent its present and future behaviour, came from references in literature and information from manufacturers [16–18]. On the basis of this information, and bearing in mind the theoretical value of the energy conversion of hydrogen, HHV, a structure has been proposed (2), that has provided a fairly satisfactory result (Fig. 2)

$$E_E = k_0 e^{-t/T} + k_1. \qquad (2)$$

3.2.2. Auxiliary equipment, treatment and compression of the gases

The electricity consumption for this equipment varies depending on the size of the electrolysis system. On average, each one represents 12% of the electrolyser consumption [18, 19]

$$E_A + E_C = 0.24 E_E \qquad (3)$$

and the total consumption of electricity is

$$C_T = E_E + E_A + E_C = 1.24 E_E. \qquad (4)$$

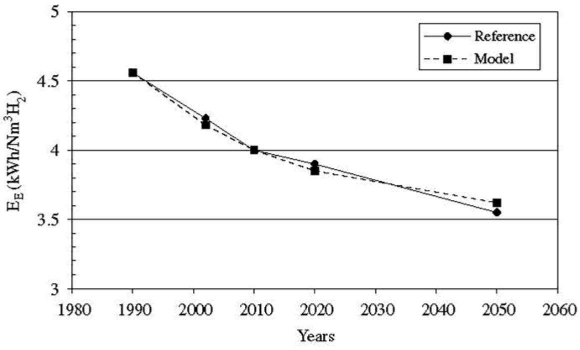

Fig. 2 – Energy efficiency
Рис. 2 – Энергоэффективность

4. Total cost model

The preparation of a total cost model for the production and use of hydrogen for energy purposes in Venezuela, involves preparing and then interconnecting the partial models for each of the stages examined: production, storage and transport, distribution and end-uses. This procedure, as well as following the logical sequence for the physical process, provides an analysis of the results. In this case, the cost model for the production stage will be developed.

5. Production cost model

In general, the cost models for the production of hydrogen follow the same structure, which consists of dividing costs into energy and non-energy, only differing in the details. For this purpose, several models have been proposed in [6,20,21] that share various equations, each of which deal with a specific aspect of the cost structure. On the basis of this, in our model, three cost modules were established: (1) Consumption, (2) Investment and (3) Operation and maintenance. Fitting these modules together provided us with the production cost model.

5.1. Consumption cost module

5.1.1. Cost of electricity

The equation used to estimate this cost includes: (a) the total consumption of electricity (Eq. (4)); (b) the production of hydrogen (Eq. (1)); and (c) the industrial electrical tariff, whose variation is satisfactorily modelled in a line graph (Fig. 3, Eq. (5))

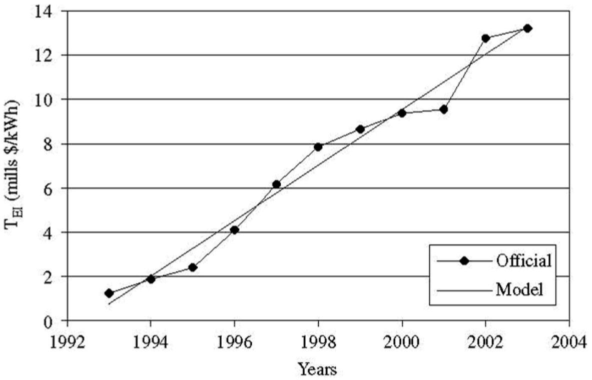

Fig. 3 – Industrial electricity tariff
Рис. 3 – Промышленный тариф на электроэнергию

$$T_{EI} = 1.2535t - 0.4985, R_2 = 0.9761. \qquad (5)$$

The cost of electricity for the production of electrolytic hydrogen is

$$C_{EE} = P_H C_T T_{EI}. \qquad (6)$$

5.1.2. Cost of water

The water consumption for hydrogen production, including cooling, averages 1 l/N m^3 H$_2$ [17]. The low tariff for this consumption in Venezuela—around

10−4 \$/l—and the estimated volume of H_2 to be produced, enable the effect of this cost to be ignored, so that

$$C_{\mathrm{I}} = C_{\mathrm{EE}}. \tag{7}$$

5.2. Investment cost module

This is represented by the cost of the electrolyser, which varies considerably according to the size of the plant and vice versa, due to economy of scale. The mathematical model for this variation was prepared on the basis of the data supplied by [8, 21–23]. The mathematical expression of this is

$$C_{\mathrm{EL}} = 1499.74P^{-0.2167},\ R^2 = 0.987. \tag{8}$$

In which the power of the plant is obtained from

$$P = P_{\mathrm{H}}C_{\mathrm{T}}/DI. \tag{9}$$

The cost of installing the electrolyser

$$C_{\mathrm{IE}} = C_{\mathrm{EL}}P \tag{10}$$

with the capital recovery factor

$$F = \frac{d\ \ 1+d\ \ ^{n}}{1+d\ \ ^{n}-1} \tag{11}$$

and the investment cost

$$C_{\mathrm{INV}} = FC_{\mathrm{IE}}. \tag{12}$$

5.3. Operating and maintenance costs module

This is simply assumed as a percentage of investment costs. In this case, we also use the average of the values reported in the references we consulted [6,8,17,23,24]

$$C_{\mathrm{OM}} = \mathrm{OM}C_{\mathrm{INV}}. \tag{13}$$

5.4. General equation for the production cost model

The total cost of production would therefore be shown by

$$C_{\mathrm{TP}} = \frac{C_{\mathrm{I}} + C_{\mathrm{INV}} + C_{\mathrm{OM}}}{P_{\mathrm{H}}}. \tag{14}$$

6. Applying the model in Venezuela

The above model will be applied in Venezuela in the following cases:

1. A rural village: Quebrada Seca (866 inhabitants).
2. The parish in which the village of Quebrada Seca is located: Parroquia San Félix. (1254 inhabitants).
3. The municipal district in which Parroquia San Félix is located: Municipio Cedeño (4851 inhabitants).

Geographically, all the above are located in Monagas state, Cedeco Municipal District, in the east of the country. Case 1 is an entire rural village with no energy supply whatsoever, whereas in cases 2 and 3, the rural population with no energy supply is found by applying the percentage calculated by [10]. The simulation will be in place for a time horizon of up to 20 years as from 2000.

7. Results and analysis

Table 1 shows the costs per module and the total cost of production for all the study cases, for the year 2005. It can be seen that the value of C_{TP} diminishes as the population supplied with it increases, as a result of economy of scale (Table 3).

If we compare the values of C_{TP} with those given in references for similar values of hydrogen production, it can be seen that the values found in the Venezuelan case are much smaller, even for cases in which far larger production is involved, and therefore with a greater impact of economy of scale, Table 4. These results are strongly influenced by the low electricity tariffs in Venezuela.

The evolution of C_{TP} in the period studied shows a sustained increase in all cases (Fig. 4).

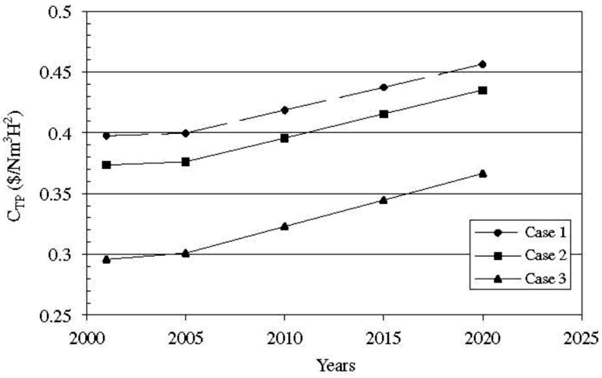

Fig. 4 – Evolution of production costs
Рис. 4 – Динамика производственных затрат

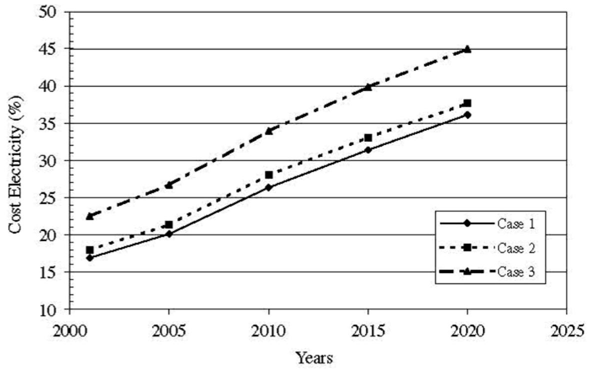

Fig. 5 – Contribution of electrical power to the production costs. Period 2002–2020
Рис. 5 – Вклад электроэнергии в себестоимость (2002–2020 гг.)

The increase in costs, in particular in C_{EE}, predominates over the increase in PH, particularly after 2010, as shown by the change in the slope of the curve. This behaviour can be explained because, as from that year, the improvement in efficiency (Fig. 2), is not as acute and, therefore, nor is its effect on costs. It should also be noted that the degree of progress of C_{TP} is less as the population increases, due to the effect of economy of scale.

As for electrical power, its contribution in percentage to the total cost increases throughout the study period (Fig. 5), at the expense of investment costs and due mainly to the nonlinear nature of the electrical energy cost model (Eq. (6)).

It should also be noted that, for the same year, the contribution in percentage increases with the increase in population.

Table 3

Costs of production of hydrogen

Таблица 3

Стоимость производства водорода

Considered case	C_{EE}	C_{INV}	C_{OM}	P_H **(Nm^3H_2/y)**	C_{TP}
Case 1	4486	12,504	5321	55,814	0.3997
Case 2	6365	16,435	6993	79,194	0.3762
Case 3	24,168	47,421	20,179	306,285	0.3011

Year 2005.

Table 4

Comparison of costs with bibliographic results

Таблица 4

Сравнение стоимости с литературными данными

	P_H **($N\ m^3\ H_2/y$)**	C_{TP} **($\$/N\ m^3\ H_2$)**
Model proposed (Case 2, 2005)	79,000	0.3762
[17]	78,000	1.7010
[25]	11,580	0.6385
[23]	34,000,000	0.3674
[8]	59,000,000	0.9200

8. Conclusions

A non-linear mathematical model has been prepared to show the costs of the production of hydrogen via electrolysis, using hydroelectricity in Venezuela. The model is comprised of several modules which each deal with one of the components of the total production cost: consumption, investment, and operation and maintenance. The mathematical equations used for each of these modules were obtained from historical data, manufacturers' information and references. The production cost model was applied to different rural Venezuelan villages that had no permanent energy supply. For the cases analysed, the total cost of the production of hydrogen was much lower than those reported in the references we consulted for similar production levels and even for others with more favourable conditions in terms of economy of scale. The percentage of cost for electricity was between 17% and 45%, depending on the year and the population involved. Finally, it may be concluded that the production of electrolytic hydrogen from hydroelectricity is, in comparative terms, highly advantageous in the case of Venezuela.

Acknowledgements

The authors are grateful for the financial support of the CDCHT of the Universidad de Los Andes, Mŭrida, Venezuela, through the grant NUTA-C-020-03-02-B.

References

[1] Dunn J. Hydrogen futures: toward a sustainable energy system. *Int. J. Hydrogen Energy*, 2002;27:235–64.

[2] Galli S., Stefanoni M. Development of a solar hydrogen cycle in Italy. *Int. J. Hydrogen Energy*, 1997;22:453–8.

[3] Mourelatos A., Diakoulari D., Papagiannakis L. Impact of CO_2 reduction policies on the development of renewable energy sources. *Int. J. Hydrogen Energy*, 1998;23:129–49.

[4] Abdallah M., Asfour S., Veziroglu T. Solar–hydrogen energy system for Egypt. *Int. J. Hydrogen Energy*, 1999;24:505–17.

[5] Lufti N., Veziroglu T. Solar–hydrogen demonstration project for Pakistan. *Int. J. Hydrogen Energy*, 1992;17:339–44.

[6] De Souza S. Hydrogen energy as a possibility of utilization of the secondary energy of brazilian hydropower plant of Itaipu. Proceedings of the 13th world hydrogen energy conference. Beijing, China: 2000. p. 116–21.

[7] de Lima L., Veziroglu T. Long-term environmental and socio-economic impact of a hydrogen energy program in Brazil. *Int. J. Hydrogen Energy*, 2001;26:39–45.

[8] Da Silva E., Marin A., Ferreira P., Camargo J., Apolinario F., Pinto C. Analysis of hydrogen production from combined photovoltaics, wind energy and

secondary hydroelectricity supply in Brazil. *Solar Energy*, 2005;78:670–7.

[9] Venezuela: country analysis brief, at _http://www.eia.doe.gov/emeu /cabs_; 2005.

[10] PODER: Plan Operativo de Energías Renovables, Dirección de Planificación y Economнa de la Energía. Ministerio de Energía y Minas, Venezuela, 2002.

[11] PODE: Petróleo y otros datos estadísticos, Direcciyn de Planificación y Economía de la Energía. Ministerio de Energía y Minas, Venezuela, 2004.

[12] Martínez J. Energías renovables. Potencial energético de los recursos aprovechables. División de Alternativas Energéticas, Ministerio de Energía y Minas, Venezuela, 2001.

[13] Reporte Socio-Demográfico. Instituto Nacional de Estadística, Venezuela, 2004.

[14] CAVEINEL. Cámara Venezolana de la Industria Eléctrica. Estadísticas Consolidadas, 2004, at _http://www.caveinel.org.ve/estadнsticas_.

[15] CIER, Comisión de Integración Energética Regional: Precio de la Energía a Consumidores Finales, 2006. At _http://www.cier.org.uy/2005/7_.

[16] Kruger P. Electric power requirement in the United States for large-scale production of hydrogen fuel. *Int. J. Hydrogen Energy*, 2000;25:1023–33.

[17] Ivy J. Summary of electrolytic hydrogen production. NREL/MP-560- 36734, 2004.

[18] Cloumann A., d'Erasmo P., Nielsen M., Halvorsen B. Analysis and optimization of equipment cost to minimize operation and investment for a 300 MW electrolysis plant. *Proceedings of the 12th world hydrogen energy conference*, 1998. p. 143–9.

[19] Vidueira J., Contreras A., Veziroglu T. PV autonomous installation to produce hydrogen via electrolysis, and its use in FC buses. *Int. J. Hydrogen Energy*, 2003;28:927–39.

[20] Bockris J. The origin of ideas on a hydrogen economy and its solution to the decay of the environment. *Int. J. Hydrogen Energy*, 2002;27:731–40.

[21] Thomas C.E., Kuhn I. Electrolytic hydrogen production infrastructure options evaluation. NREL/TP-463-7903, 1995.

[22] Oulette N., Rogner H., Scott D.S. Hydrogen from remote excess hydroelectricity. Part I: production plant capacity and production cost. *Int. J. Hydrogen Energy*, 1995;20:865–71.

[23] Padry C.E.G, Putshe V. Survey of the economics of hydrogen technologies. NREL/TP-570-27079, 1999.

[24] Basye L., Swaminathan S. Hydrogen production costs: a survey. DOE/GO/10170-118, 1997.

[25] Moore R., Raman V. Hydrogen infrastructure for fuel cell transportation. *Int. J. Hydrogen Energy*, 1998;23:617–20.

4th Green & Sustainable Chemistry Conference

5-8 May 2019 | Dresden, Germany

As with previous events in the series, this high-level conference will address a range of broad topics highlighting the role of chemistry in contributing to achieving the Sustainable Development Goals, including in developing countries.

Abstracts are invited for oral communications and posters to supplement the invited lectures

Other conferences in this field are focused mainly on the synthesis and technical aspects of green chemistry. To contribute in a long-term, viable and globally applicable manner to the Sustainable Development Goals, a much broader approach and knowledge exchange is necessary. The goal of the conference is therefore to bring together international researchers from academia and industry, from authorities and other institutions, from all parts of the worlds, to communicate and share the latest developments across the broad and diverse fields of green and sustainable chemistry.

Topics will include:

- Energy conversion and storage
- Inorganic resources and materials
- Recent developments in green synthesis
- Bioresources
- Photochemistry and photocatalysis
- Start-ups and sustainable chemistry
- Synthesis and catalysis
- Sustainable chemistry in environmental science
- Sustainable pharmacy
- Sustainable chemistry in developing countries
- Sustainable chemistry in economy
- Green and sustainable chemistry education

Elsevier Foundation Green and Sustainable Chemistry Challenge

Another unique feature of this conference is the Elsevier Foundation Green and Sustainable Chemistry Challenge

www.elsevier.com/events/conferences/green-and-sustainable-chemistry-conference