

Hydroelectricity introduction through hydrogen as fuel for long-distance passenger buses: a sustainable alternative for Paraguay

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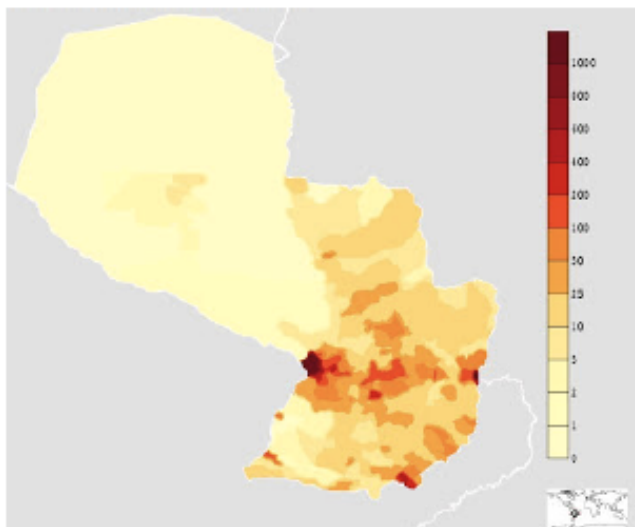


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Summary

- The replacement of current diesel buses with hydrogen-powered buses for long-distance passenger transport is discussed in this work and different models of hydrogen production and distribution are analyzed.

Paraguay at a Glance

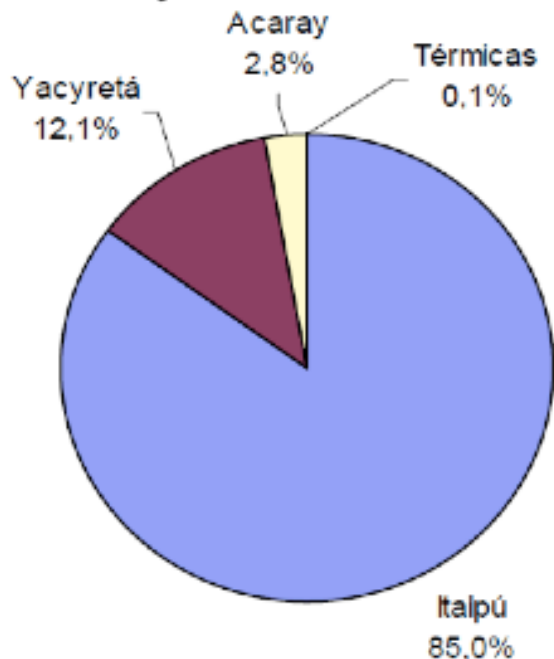


- Population: 6.57×10^6 (2012 est.)
WB
- Total Area: 406.752 km^2
- Density $16,4 / \text{km}^2$
- 1134 kWh per capita @2010 WB
- GDP (PPP) per capita: US\$ 5500.75 (@ 2012)
- GDP (PPP): US\$ 41.1 billion (@ 2012)
- GDP by sector:
agriculture: 19.8 %;
industry; 19.4 %;
services; 60.8 % (2012 est.)
- GDP growth 13% (2013)

Hydraulic Generation

Installed capacity = 8.820 MW

Generation capacity ~ 78.000 GWh/year



ITAIPU BINACIONAL

Cap = 7.000 MW



CENTRAL ACARAY

Cap = 210 MW

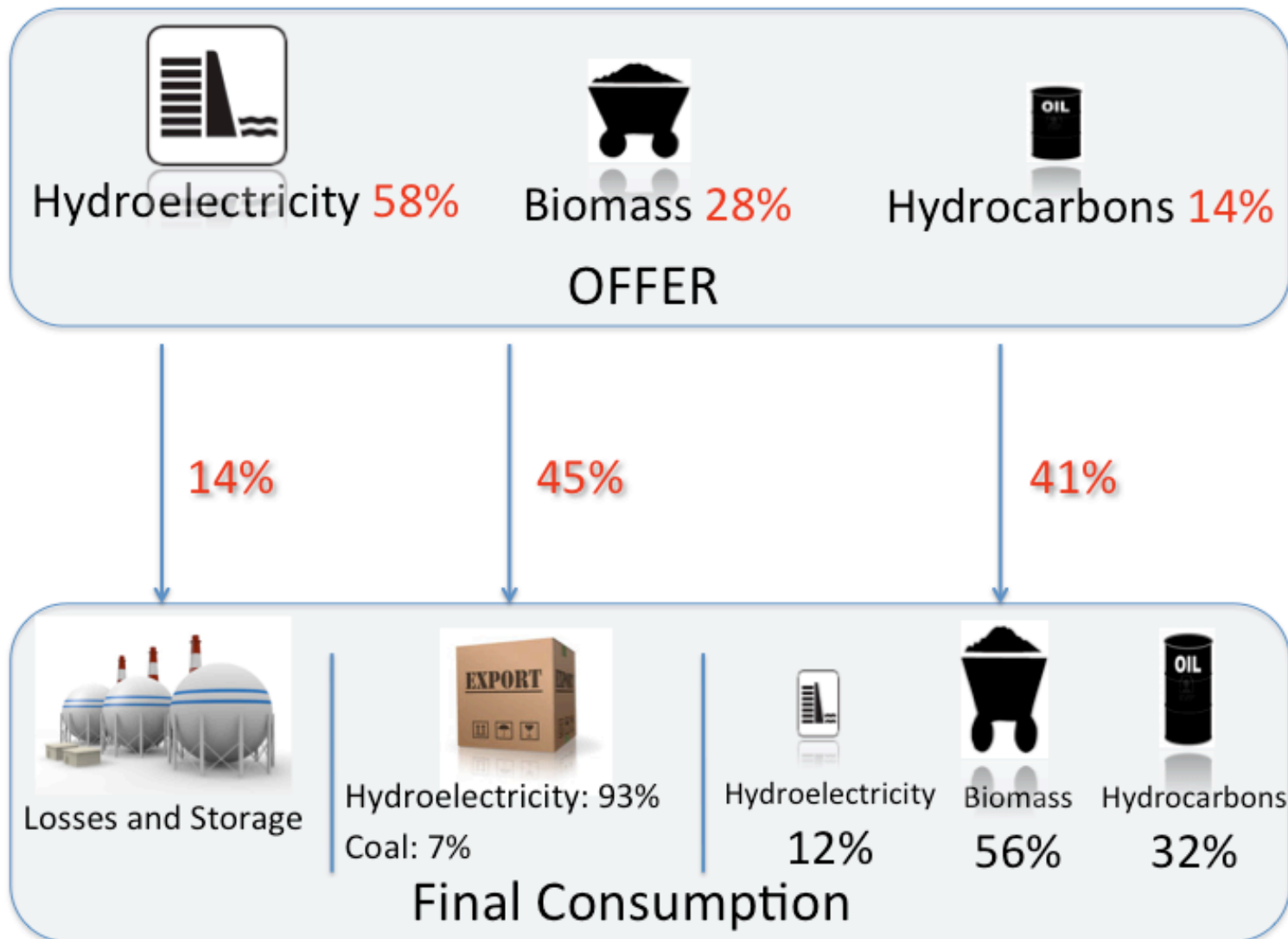
Cap = 1.600 MW



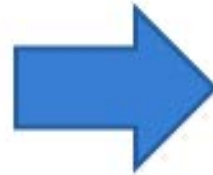
YACYRETA BINACIONAL

* *Electric consumption per capita ~ 1,300 kWh*

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Proposal



47.9 kWh/kg



2.28 kWh/kg



Passenger Transport Sector

ROUTE	ASU - CDE
SERVICE	12 private operators
ROUND-TRIPS PER DAY	9 per company
CARRYING CAPACITY	60 passengers (80%) 25 passengers (20%) <i>Executive Service</i>
TOTAL FLEET	60 buses
FUEL	Diesel

Source: DINATRAN, 2014

Selected Route



Two main urban areas of Paraguay: Asunción (capital city) and Ciudad del Este, located at a distance of 320 km from each other.

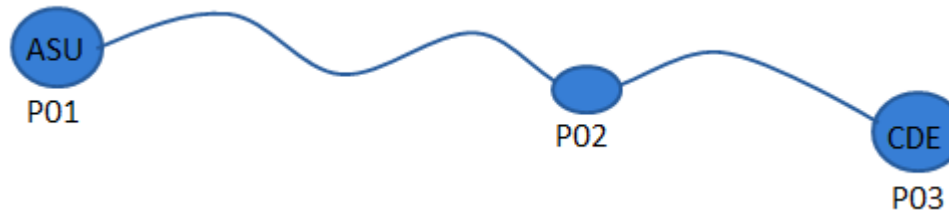
Referenced hydrogen-powered bus



Features	Value
Dimensions (length)	12.6 m
Seating Capacity	30
Motor Power	230 kW
Fuel Cell Power	205 kW
Fuel	CGH
Fuel Storage	45 kg
Consumption	15 kg/100 km
Autonomy (range)	300 km

- Demonstration project being addressed by Brazilian Ministry of Mines and Energy and funded by the Global Environment Facility under United Nations Development Program implementation.

Scenarios Configuration



A	B1	B2	B3
One hydrogen bus	Replacement of 20% of total fleet	Replacement of 20% of total fleet	Replacement of 20% of total fleet
Three refueling stations, hydrogen production in each one	Three refueling stations, hydrogen production in P01 and P03, delivery to P02 by trucks	Three refueling stations, hydrogen production in each one	Two refueling stations, theoretical increased autonomy of the referenced bus

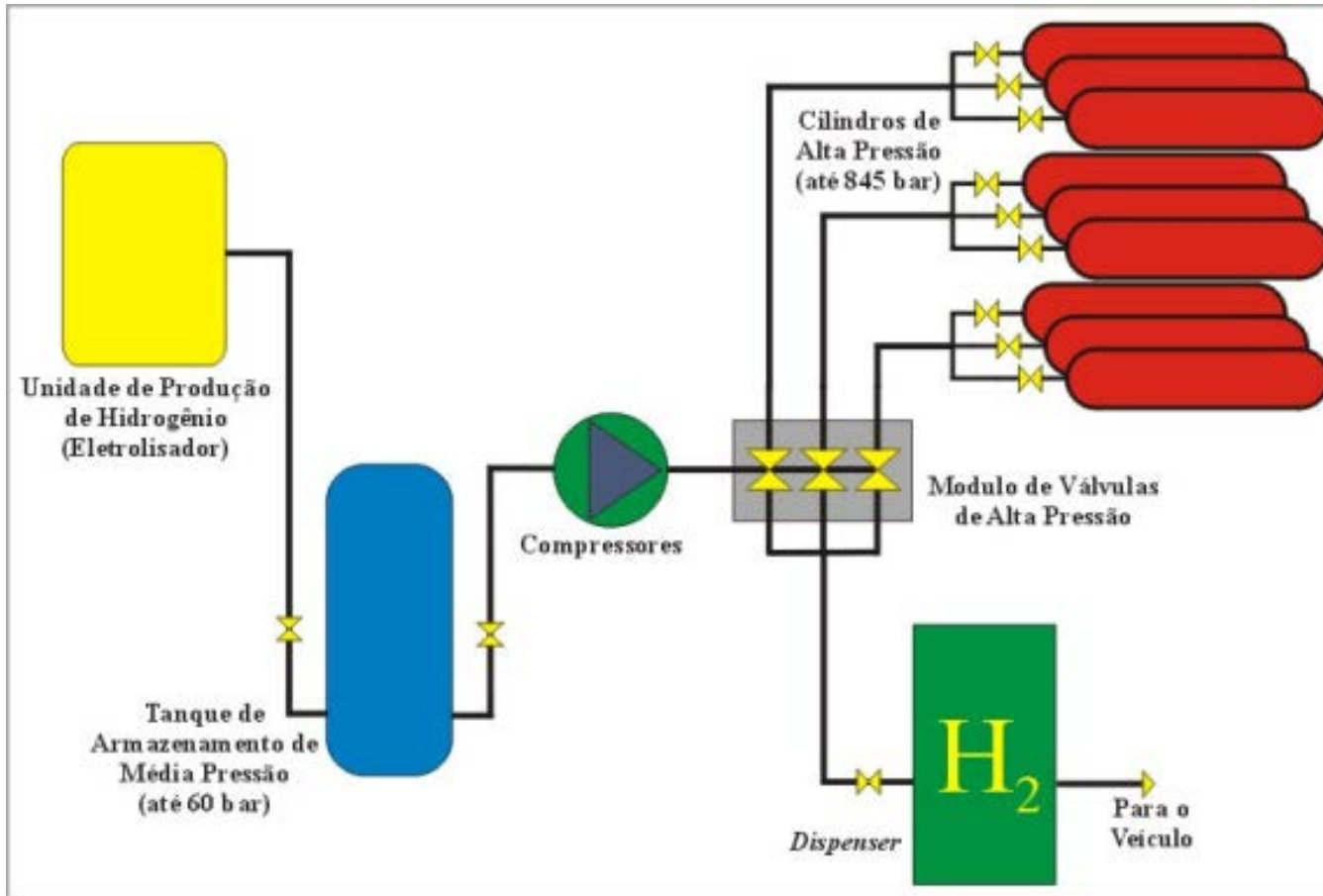
Methodology

Assumptions	Value	Unit
Rate of Return	15	%
Equipment life time	15	year
Capital Recovery time	10	year
Operation and Maintenance Cost	6% TCC	USD
Engineering/Construction Cost	30% TCC	USD
Contingency Cost	10% TCC	USD
Water Cost	0.939	USD/m ³
Electricity Cost	0.035	USD/kWh

Electrolyzer and main equipment cost from industry

Based on PhD Thesis: *Hydrogen highway Brazil – Paraguay: technical, economic and environmental analysis (2013)*

Sizing Refueling Stations

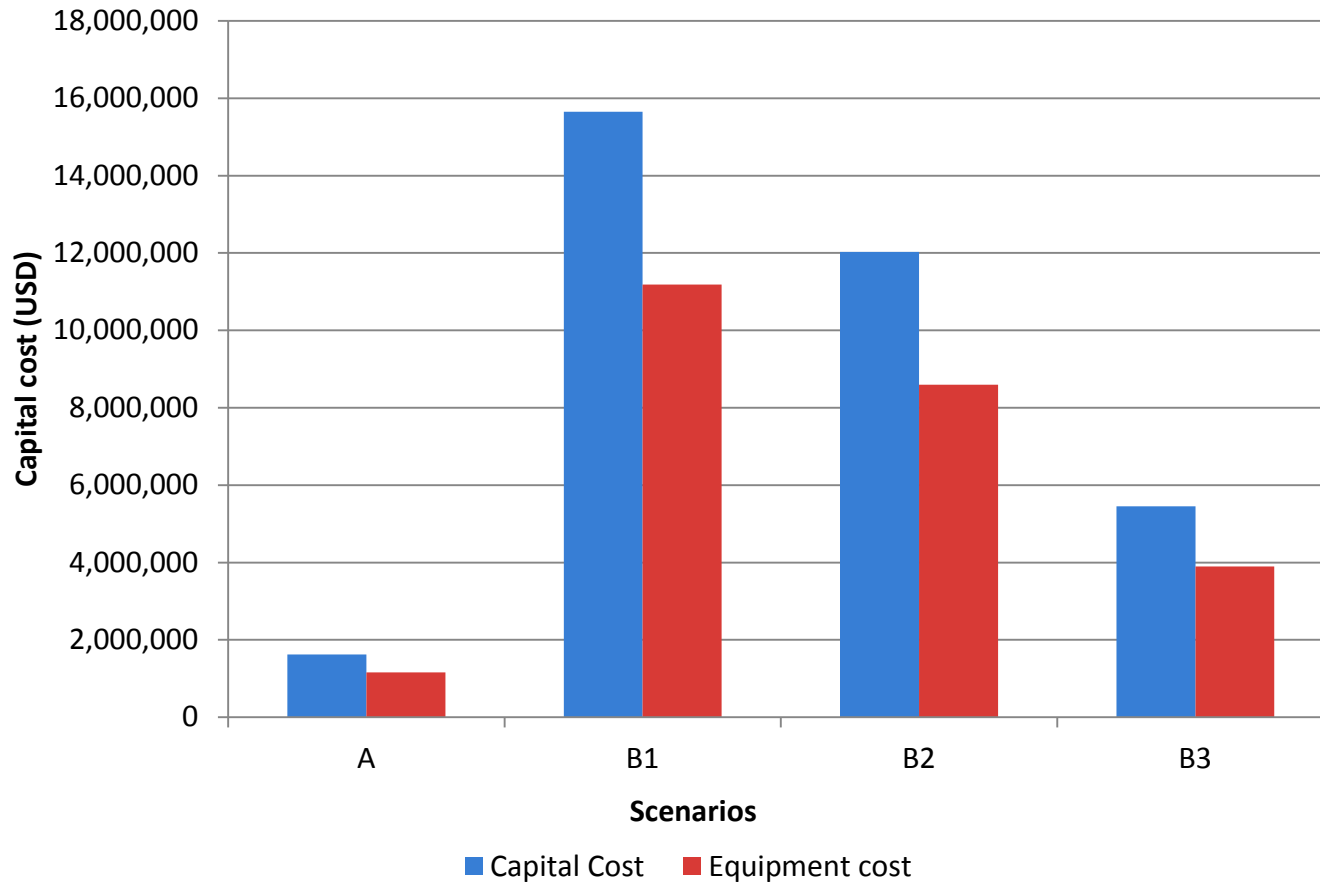


Source: Ferreira, 2007

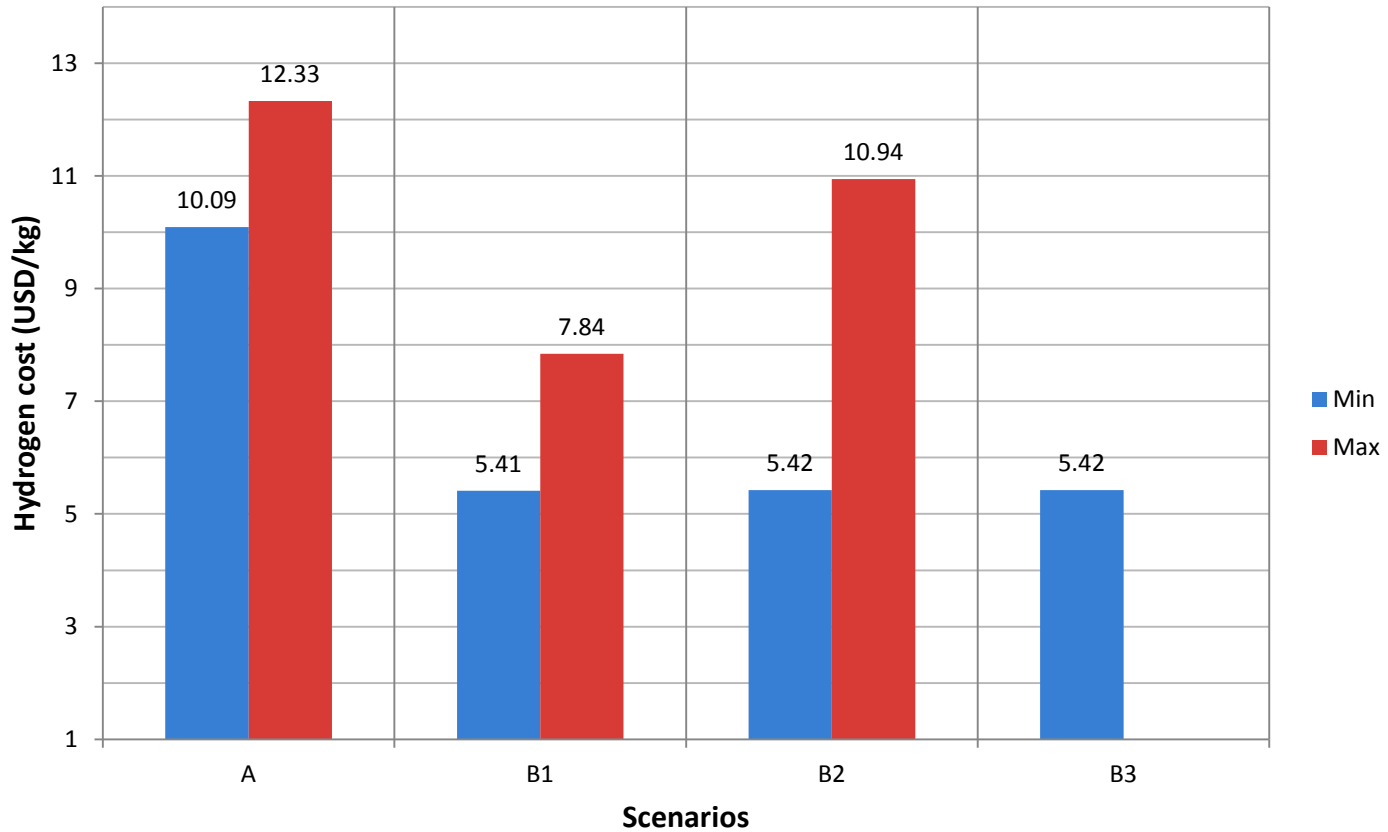
Results – Main costs

	Unit	P01	P03	P02
Fleet	...	1	1	1
Electrolyzer capacity	kg/h	2.08	3.42	0.00
Storage capacity	kg	45	73.8	28.8
Electricity Demand	kWh/year	457,893	750,944	0
Water Demand	m ³ /year	101	166	0
Input cost	USD/year	16,121	26,439	N/A
Equipment capital cost	USD	470,091	607,897	81,589
Capital cost	USD	658,127	851,055	114,224
Annual cost	USD/year	93,667	121,125	16,257
Hydrogen cost	USD/kg	12.33	10.09	N/A

Results - Investment cost



Results - Production cost



Conclusions

- The proposal is presented as a sustainable alternative (taking advantage of a renewable energy resource such as hydropower).
- Option for to increase the usage of electricity in Paraguay.
- This kind of project could position the country in the world economy map of hydrogen.
- Despite the simplifications made, the study indicates some important points to be considered in a practical discussion about hydrogen technology use in the long-distance transport sector.
- The main strategy should be to increase the autonomy of this type of vehicles in order to make its inclusion easier in the regular transportation service.

ACKNOWLEDGMENT

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Thank you very much!!!

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