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Research Report: ZLC-2008-9
Modeling the Supply Chain within Spain for Hydrogen Fuel Produced Using Sustainable Inputs
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Modeling the Supply Chain within Spain for Hydrogen Fuel Produced Using Sustainable Inputs

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EXECUTIVE SUMMARY

In an era of surging petroleum prices and finite reserves, and with food shortages across the globe, for which grain-based ethanol has been demonized, the demand for a viable and sustainable alternative to petroleum-based fuels has become apparent. While hydrogen, generated from renewable energy sources, may not be the panacea for global energy needs, it is definitely an option that should be considered for future energy portfolios.

While the technologies for the generation, processing, and handling of hydrogen fuel may no longer be in their infancies, there is still much room for growth. The uncertainty about which method is more viable for producing and transporting hydrogen, and the fairly non-compatible nature of current petroleum fuel storage, transportation, and distribution equipment with hydrogen are obvious concerns. These issues, coupled with the uncertainty in predicting adoption by consumers, have led to difficulties in designing optimal supply chains for hydrogen.

The objective of this thesis is to find the most cost effective manner to design a hydrogen supply chain within Spain using electricity generated by existing windfarms.

This thesis is unique due to the fact that it incorporates a detailed geographic representation of windfarms and the power grid. Also, few prior models take into consideration the use of electrolysis on-site, using the existing electric grid to transport electricity, in addition to having centralized facilities and transporting hydrogen via truck or pipeline.

In order to account for the multiple complications of designing a national hydrogen supply chain, this thesis has set forth the following scenarios and constraints for Spain, the country of study:

- **Production technology:** To be as sustainable as possible, hydrogen is produced by electrolysis using electricity generated by windfarms owned and operated by Acciona.

- **Demand scenarios:** Two demand scenarios are run, one with 5% adoption, the other with 20% adoption.

- **Supply scenarios:** Five supply scenarios are run, the first two with unconstrained production capacity, and the last three with constrained capacity. Scenario #1 has no toll to

transport electricity via the grid, scenarios #2 and #3 have the highest tolls, and the toll diminishes across scenarios #4 and #5. All five supply scenarios are run for demand scenario #1, and supply scenarios #3 and #5 are run for demand scenario #2.

- **Sites:** All activities (except for liquefaction) may take place at windfarms, substations, or on-site/demand locations.

- **Products and transportation:** Hydrogen may be stored and transported at 2,700 psi (180 atm), 7,000 psi (476 atm), or as liquid H_2, and can also be transported (only by pipeline) at 1,000 psi (68 atm). Electricity can be transported either by direct line from windfarms or through the electric grid via substations.

The following observations can be drawn from the results of the simulations:

- As the toll increases within supply scenarios for compressed hydrogen, production tends to shift to a more centralized scheme.

- While the average cost difference between 2,700 and 7,000 psi is not vast, the standard deviation is almost half when 7,000 psi hydrogen is produced and transported; therefore, this is also the more robust supply scenario within the first demand scenario.

- While the transport cost of liquid hydrogen is significantly lower than that for transporting any compressed form, the cost to liquefy hydrogen is great enough to make the total cost for this form's supply scenario much higher than any other form.

- When demand quantity and location density are greater (demand scenario #2), 2,700 psi hydrogen becomes much more attractive. It is less costly than 7,000 psi hydrogen (and drastically less costly than liquid hydrogen) and has a somewhat similar standard deviation to 7,000 psi hydrogen.

- Fixed costs, i.e. fixed costs of substation connections and direct line construction, are significantly lower than the variable cost component of the total cost for any given scenario. This is due to the fact that the variable cost components derived from H2A already account for fixed costs within the cost per kg (variable cost)

- As transport via pipeline is significantly more expensive than any other mode, this option is never chosen in any scenario.

The conclusion from this thesis, as it applies to companies interested in entering this burgeoning field, is that total costs and optimal supply chain designs are highly dependent upon factors which may very likely be out of their control or bargaining power, i.e. electric grid "tolls". For hydrogen projects to be widely invested in, governments may need to become involved to make sure that a fairly stable pricing environment exists.