# Renewable Energy Storage and Production in Argentina: An Assessment of the Viability of Substitute Natural Gas

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## Abstract

*This study analyzes the feasibility of implementation of a relatively new and unique renewable energy process, whereby wind energy is converted to synthetic natural gas (SNG), in Argentina. It begins with an explanation of the chemical process, followed by a look at Argentina's energy matrix, policy and current efforts in the renewable energy field, particularly wind and electricity. Additionally, this study looks at hydrogen production, as it is already occurring in Argentina and is the first step in the production of SNG. Much detail is given to the implementation costs of SNG within Argentina's current energy system, complete with a pricing analysis. This paper continues with an outline of the benefits and challenges of utilizing synthetic natural gas as a form of power in Argentina, determining that SNG production will benefit Argentina, as it is clean, renewable, and cost-effective, and will benefit the economy and increase energy independence. The study determines that SNG is both economically viable and beneficial for Argentina, particularly when compared to fossil fuels and imported natural gas.*

**Acknowledgements**

This paper would not have been possible without the help of multiple individuals in the energy community in Argentina, Germany and the United States. We would like to extend our deepest gratitude to the following individuals and organizations for donating their time, efforts and information: The Inter-American Development Bank (IDB), specifically Juan Paredes and the Energy and Infrastructure Department of the Bank; the Embassy of Argentina in Washington, D.C., specifically Guillermo Rodolico and the Minister and Secretary of Commerce and Business Development and the Bureau for Energy Development at the Embassy of Argentina; Solar-Fuel GmbH, the Center for Solar Energy and Hydrogen Research (ZSW); Fraunhofer Institute for Wind Energy and Energy System Technology; Michael Matera, Global Outcomes, a business advisory firm; Ambassador Alfredo Raul Morelli and Consejero Sergio Servin, The Argentine Ministry of Foreign Affairs and Trade; Sebastian Kind, Aires – Renewable Energy Sources, a renewable energy development company; Carlos St. James, Latin American & Caribbean Council on Renewable Energy; Claudio A. Molina, Asociacion Argentina de Biocombustible e Hidrogeno; Luis Bertenasco, ENARSA PDV; Ing. Eduardo Jorge Hadad Pitasny and Constanza Diaz, Secretary of Energy, Ministry of Planning; and Sabino Mastrangelo, Ing. Daniel Geler, Ing. Jose Maria Rodriguez, Ing. Mariela Beljansky, CAMMESA.

## Methodology

This study was conducted in Washington, D.C., as well as in Buenos Aires, Argentina, during a week of in-person interviews, which took place from March 12-16, 2012. Pre-departure research was conducted to analyze the process of SNG production. Field work—interviews in Buenos Aires—was used to assess the current energy and economic infrastructure, looking closely at wind power and hydrogen production in order to determine viability of utilizing SNG to provide electricity in Argentina from an economic, financial, and infrastructural perspective.

The research for this study was facilitated greatly by our project sponsor, the Inter-American Development Bank (IDB), specifically the Energy and Infrastructure Department of the Bank. The IDB supports efforts by Latin American and Caribbean countries to reduce poverty and inequality, with an aim to bring about development in a sustainable, climate-friendly way. The IDB is the largest development bank in Latin America and the Caribbean, with a strong commitment to achieve measurable results, increased integrity, transparency and accountability.[1]

Additional support for this research was provided by the Embassy of Argentina in Washington, D.C., specifically the Minister and Secretary of Commerce and Business Development and the Bureau for Energy Development at the Embassy of Argentina.

In addition to the aforementioned sponsors, information was obtained from international organizations in the energy industry and that, more specifically, work with the SNG technology that was essential to the content of this paper. These organizations included (1) Solar-Fuel GmbH, (2) the Center for Solar Energy and Hydrogen Research (ZSW), and (3) the Fraunhofer Institute for Wind Energy and Energy System Technology.

While in the field, in Buenos Aires, Argentina, meetings were held with multiple organizations including Global Outcomes, the Ministry of Foreign Affairs and Trade, ENARSA PDV, CAMMESA and the Argentine Secretary of Energy in the Ministry of Planning. These individuals and organizations provided information about the Argentine energy sector, government policies on renewable energy, infrastructure, hydrogen development, and other information relevant to answering the question of feasibility of implementing SNG into the country’s energy matrix. A full list of those who contributed to this study is listed above in the Acknowledgements section.

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[1] The Inter-American Development Bank, http://www.iadb.org/en/about-us/about-the-inter-american-development-bank,5995.html.

## Introduction and Hypothesis

This research focuses on the production of synthetic methane, referred to hereafter as Substitute Natural Gas (SNG), as a source of renewable energy in Argentina. Renewable SNG is a newly developed source of clean energy that allows for the seasonal storage of a fluctuating source of energy—a noteworthy benefit when compared to traditional renewable energy sources.

SNG is particularly relevant in Argentina as it can be used in the same manner and medium as natural gas, which comprises approximately two-thirds of the country's current energy matrix with a vast distribution network in place.

Additionally, as renewable SNG production is dependent upon wind power, selecting a region with optimal preexisting conditions, i.e. a high wind capacity, is essential to successful implementation. As 70 percent of Argentina's territory maintains an efficient wind capacity of the necessary 35 percent or above, the nation is an ideal locale for SNG production. Renewable SNG has already been implemented successfully in Germany, but the nation possesses less than optimal wind conditions, particularly when compared to Argentina.

Argentina's natural resources and existing infrastructure make the nation the ideal candidate for implementation of this process. Therefore, this study hypothesizes SNG to be a beneficial and optimal source of renewable energy for Argentina, providing the nation with economic, political, and security benefits. The main goal of this study is to determine the feasibility of SNG production in Argentina, focusing on the generation cost and pricing competitiveness when compared to other energy sources.

## Synthetic Natural Gas

As fossil fuels continue to be over-exploited, over-used, and in danger of depletion, the world must turn to new energy sources in order to maintain the necessary production levels that allow for continued growth and prosperity. In recent years, there has been a strong movement towards wind and solar power development. The main problem with a greater dependence on these renewable energy sources is the lack of reliability of the sources themselves—the wind is never constant and the sun is only shining a fraction of the day. As will be examined further in subsequent sections, Argentina has an enormous natural potential for wind energy. However, the country struggles to maximize this resource, due to a lack of storage capacity and the limited convertibility of wind into more usable forms.

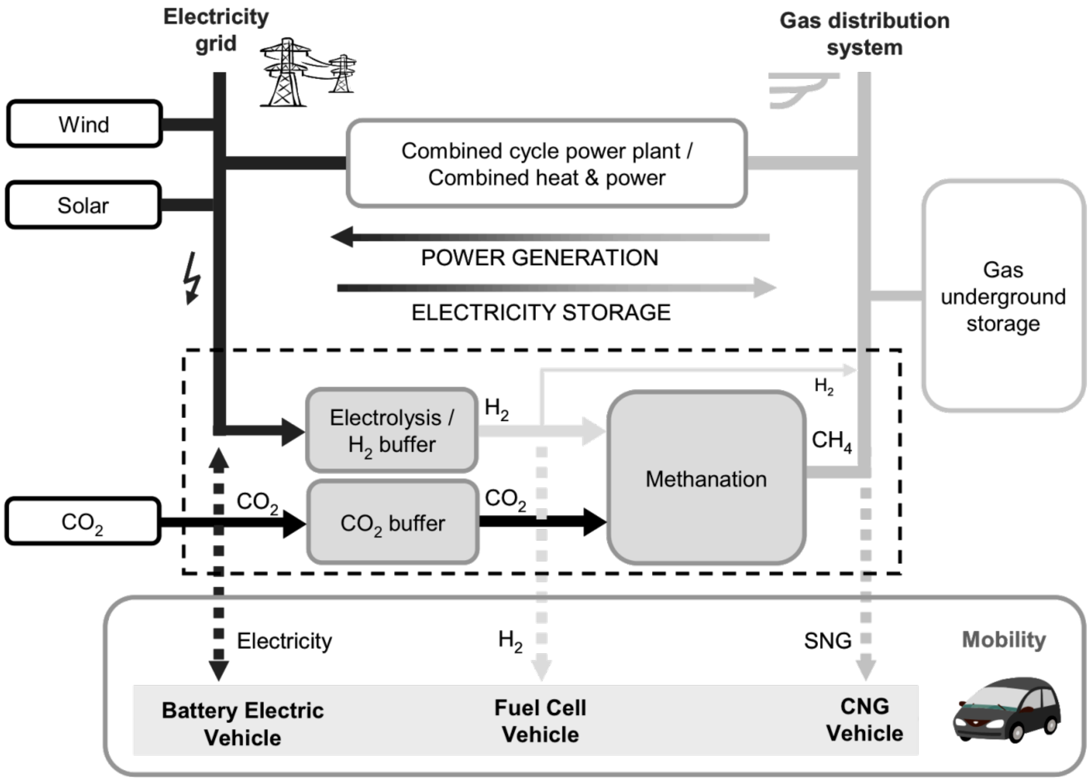
Michael Sterner, of the Center for Solar Energy and Hydrogen Research (ZSW), in collaboration with Michael Specht, of the Fraunhofer Institute, have developed a new technology that allows for the seasonal storage of wind and solar energy. Such a development will undoubtedly be of paramount importance as the Earth's raw materials continue to dwindle due to over-consumption.

Using the ZSW and Fraunhofer Institute method, wind energy is converted into synthetic methane, which serves as an energy storage medium. As mentioned, because the synthetic methane can be used as a complete substitute to natural gas, this paper refers to this substance as Substitute Natural Gas (SNG). While the concept of SNG has been in existence since the late 1970s, current production of SNG uses coal—via steam-oxygen gasification, hydrogasification, and catalytic steam gasification—as the initial source of energy.[2] The new, completely renewable method created by ZSW and the Fraunhofer Institute, however, uses only wind as the initial input energy source and serves as a much cleaner, and environmentally friendly, method for SNG production. Of particular importance for this study is the ability for SNG to be reconverted at will from a thermal state to an electric state. At this point in time, only the conversion from electricity to power is available—not power to electricity. As Sterner illustrated in his work *Renewable Energies and Energy Efficiency*, such a bidirectional linkage allows for greater stability of both the electric grid and the natural gas grid.[3]

While SNG can be created from a variety of biogases, renewable SNG is produced by using the excess electricity created from a renewable source of energy, typically wind or solar, to create hydrogen ($H_2$) via electrolysis.[4] The $H_2$ is then added to carbon dioxide ($CO_2$) using a process known as the Sabatier Reaction, and converted into methane in a thermochemical synthesis (methanation).[5] The resulting SNG can then be distributed and reconverted on demand in order to balance the natural gas and electric grid. Thus, renewable SNG can be used directly as a fuel in both thermal and liquid forms, e.g. for heating homes or in natural gas vehicles. While this paper focuses on gathering the necessary $CO_2$ from the atmosphere, the $CO_2$ can be collected from a variety of sources—including fossil power generation, Carbon Capture Storage (CCS), biogas plants, gasification, and upgraded and purified $CO_2$ from industrial processes such as lime or cement production[6]. Figure 1 illustrates the SNG process using renewable power generation.

[2] Chandel, Munish et al. "Synthetic Natural Gas (SNG): Technology, Environmental Implications, and Economics."(Durham, North Carolina: Duke University. January 2009), 4.
[3] Sterner, Michael. "Bioenergy and Renewable Power Methane in Integrated 100% Renewable Energy Systems," (Kassel, Germany: Kassel University Press, 2000), 106.
[4] Sterner, 107. Note: "H2 can also be generated directly from solar thermal energy, saving the PV inverter and electrolysis rectifier."
[5] Sterner, 107.
[6] Ibid.

Figure 1: The Renewable SNG Process




*Source:* ***Michael Specht****, "Storing Renewable Energy in the Natural Gas Grid: Methane via Power-to-Gas: A renewable Fuel for Mobility," and* ***Michael Sterner****, "Bioenergy and Renewable Power Methane in Integrated 100% Renewable Energy Systems"*

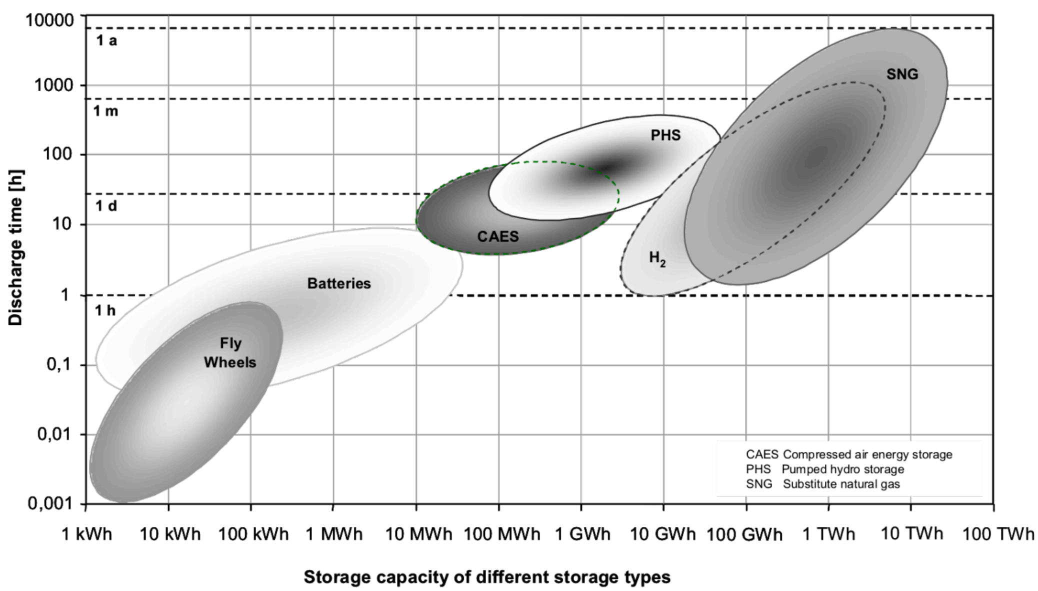
One of the many benefits of SNG is that this renewable chemical energy can be stored in the existing natural gas infrastructure, which makes this technology extremely attractive for countries like Argentina that already have an extensive network of natural gas pipelines. Unlike hydrogen, which requires extensive upgrades and modifications of infrastructure, the natural gas distribution, storage, and power-conversion technologies are not only top-notch but also already in place. Additionally, while to date most renewable energy is simply converted to electricity in a transportable form, direct storage of electricity is relatively limited. The available storage technologies are super capacitors (electric energy), hydropower pumped storage power plants (potential energy), and compressed air reservoirs and flywheel energy storage systems (mechanical energy).[7]

Methane's higher energy density, however, allows for larger transfer capacities in gas pipelines than in electrical power lines. As Michael Specht states in *Storing Renewable Energy in the Natural Gas Grid: Methane via Power-to-Gas (P2G): A Renewable Fuel for Mobility*, "While a high voltage direct current transmission is restricted to outputs < 7GW,

[7] Michael Specht, U. Zuberbuhler, F Bamart, B. Fiegl, V. Frick, B. Stumer, M Sterner and G Walstein. "Storing Renewable Energy in the Natural Gas Grid: Methane via Power-to-Gas: A Renewable Fuel for Mobility," 2.

[natural] gas pipelines can reach up to 70GW."[8] The result is that wind energy can be stored as chemical energy for extensive periods of time, and can also be transported over great distances while maintaining high-energy transmission levels. As Figure 2 illustrates, of the currently well-developed storage options, pumped storage power plants currently permit for the greatest periods of electricity storage, allowing for several days of storage. By comparison, batteries, fly wheels, and super capacitors only allow for less than 24 hours of electricity storage. Looking at hydrogen and SNG however—both chemical secondary energy carriers—it becomes clear that these renewable energy sources "represent the only conceivable option for seasonally storing renewable energy with a capacity in the TWh range and converting it back into electricity when required."[9] While today's energy system typically stores enough energy in the form of fossil fuels to cover several months' consumption, the electricity sector must constantly, and carefully, balance supply and demand.[10] As such, SNG serves as a viable method of long-term electricity storage that will help ease the pressure of this delicate balance of supply and demand. As will be examined in detail later, seasonal storage of renewable energy is of the utmost importance to Argentina, which experiences a wide range of peaks and troughs in energy demand during various seasons. The country has experienced severe energy shortages in recent years and the current lack of storable forms of renewable energy has both economic and political implications as it forces the country to import energy.

Figure 2: Storage Capacity




*Source: Michael Specht and Michael Sterner*

[8] Specht. 2.
[9] Specht, 3.
[10] Ibid.

The overall efficiency of the renewable power to methane process can be defined as the product of the electrolysis efficiency and the methanation efficiency.[11] The conversion efficiency of electricity-to-hydrogen is between 62 and 80 percent.[12]

As the carbon dioxide required for methanation can be acquired from several sources, however, there are several methods for methanation—each with varying efficiencies.

Each methanation process (adding $CO_2$ to $H_2$) is defined by the Sabatier Reaction—a process discovered in 1913 but never applied to energy systems. Under this process, "$CO_2$ methanation [Equation 2] is a combination of reversed endothermal water-gas-shift-reaction [Equation 3] and an exothermal CO methanation [Equation 1]."[13] Although the operational temperature range has to be adjusted to each synthesis gas, methanation synthesis is a catalytic exothermal process at temperatures of 180-350°C and pressure levels from 1-100 bars.[14]

Figure 3: Methanation Reactions

| Methanation reactions | | | |
|---|---|---|---|
| $3\ H_2 + CO$ | $\rightarrow CH_4 + H_2O(g)$ | $\Delta H_R = -206$ kJ/mol | (Equation 1) |
| $4\ H_2 + CO_2$ | $\rightarrow CH_4 + 2\ H_2O(g)$ | $\Delta H_R = -165$ kJ/mol | (Equation 2) |
| **CO-shift reaction** | | | |
| $H_2O(g) + CO$ | $\rightarrow H_2 + CO_2$ | $\Delta H_R = -41$ kJ/mol | (Equation 3) |

*Source: Michael Specht and Michael Sterner*

According to the ZSW method, there are three different ways for methanation to occur: biogas to SNG, biosyngas to SNG, and atmospheric $CO_2$ to SNG. While Appendix 1 describes the efficiencies and methanation processes in further detail, current methanation from a biosyngas with the main components being $H_2$, CO, and $CO_2$ has an efficiency of approximately 75-85 percent.[15] As a larger quantity of $CO_2$ must be absorbed from the atmosphere than from a gas already containing relatively high volumes of $CO_2$, recovering $CO_2$ from the atmosphere reduces the overall efficiency to 48 percent.[16] This paper will focus specifically on atmospheric $CO_2$ absorption, however, as this is the only methanation in which direct input and output energy values are known. As this is the most inefficient of the three proposed methods, higher generation costs can and should be expected.

The resulting efficiency of SNG generation from the combination of electrolysis efficiency and methanation efficiency is in the range of 46-75 percent—on average 63 percent.[17] As

[11] Sterner, 108.
[12] Ibid.
[13] Sterner,109.
[14] Ibid.
[15] Specht, 8.
[16] Sterner, 110.
[17] Ibid.

most standard gas power generating technologies, such as gas turbines and Combined Heat and Power (CHP) plants, maintain an overall efficiency of approximately 60 percent, SNG-to-power efficiency is comparable to these well-developed technologies.[18]

In order to maximize the potential of SNG production, remote, sparsely populated destinations with high wind speeds should be exploited—of which Argentina has many. As SNG can be transported at high energy levels over long distances via gas pipelines, an existing infrastructural network of natural gas pipelines is essential. Taking these considerations into account, this study has chosen the Patagonia region of Argentina as an ideal destination for the combination of wind farms and an SNG plant to tap the full potential of SNG generation.

**Wind Energy in Argentina**

Rich in natural resources and arable land, Argentina is uniquely poised to be a top producer of clean, renewable energy. Coming in as the eighth largest country in the world in terms of landmass, yet possessing only a total population of 40 million citizens, Argentina possesses tremendous potential for wind power generation, and, thus, potential for SNG production.

According to research carried out by CADER, 70 percent of Argentina's territory is capable of generating efficient wind-based energy.[19] Wind power efficiency is measured in capacity percentage, with anything above 35 percent capacity considered efficient. Thus, if a given region has wind forces capable of moving a wind turbine at more than 35 percent capacity, the energy generated by that turbine is considered to be of optimal quality. In order to reach this capacity, wind must consistently (or somewhat consistently) blow between 7 and 9 meters per second (m/s).

In the central and southern regions of Argentina, winds consistently reach speeds of 9-to-12 m/s, implying capacity factors above 45 percent—considered extremely efficient for energy generation ability. To better contextualize these numbers, the average wind capacity factor in Europe is 25 percent and the average electricity consumption produced from wind in 2011 was 6.3 percent. Considering Argentina has a surface equal to 90 percent that of Europe and 70 percent of Argentine territory has excellent capacity for wind energy generation, the potential held by this clean, renewable energy source is ripe for realization. Theoretically, Argentina has a potential of wind generation that could reach more than 2,000 GW[20]. The figure below illustrates wind speed and capacity across Argentina measured at the height of 50 meters above ground. The yellow area denotes capacity above 35 percent.

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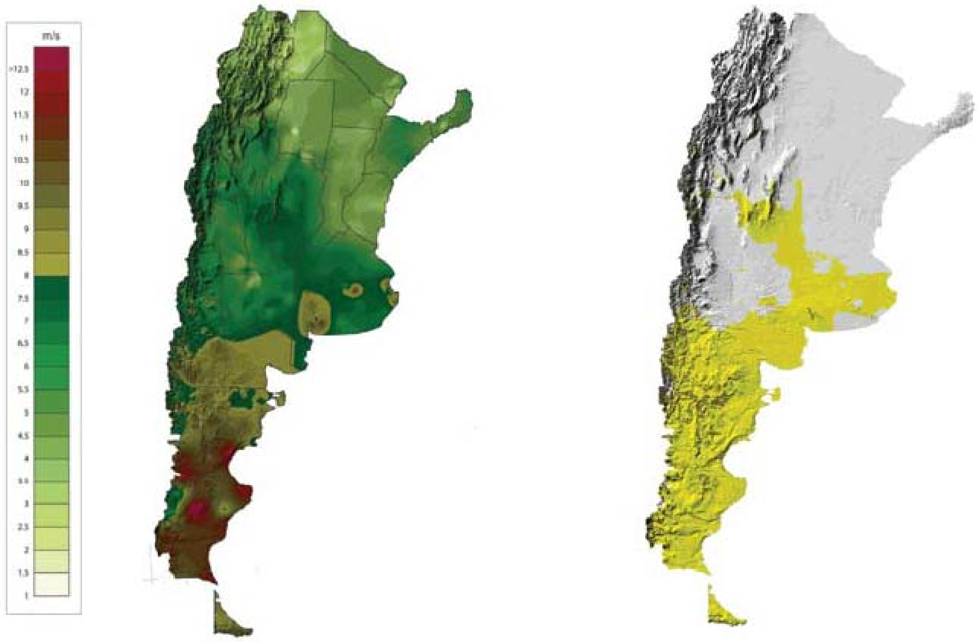
[18] Ibid.

[19] "Technical Report, An Evaluation of Financing for the Selected Projects," (Buenos Aires: GENREN. 2010), 1.

[20] Idiarte, 2010, 15.

Figure 4: Wind Speed and Capacity Across Argentina




Source: CADER (2009; from the Regional Center of Wind Energy)

While the tremendous potential for wind power development due to pre-existing optimal conditions becomes clear by looking at the figure above, Argentina has struggled with wind power legislation. As a result, legislation has evolved over the last few decades through inefficient trial and error. In 1998, Law #25.019 passed a wind and solar energy promotion resolution that aimed at attracting the private sector with: (1) a basic subsidy of ARG$0.01per kWh for the first 15 years of the enterprise, and (2) a value-added tax reimbursement stretched out over time. By 2006 however, it became clear that these incentives were not generating sufficient interest in the development of wind—or solar—energy development. Therefore in 2007, the government issued Law #26.190—which was not enforced until 2009—to supersede the law passed in 1998. Law #26.190 provided the following: (1) a basic subsidy of ARG$0.015 per kWh of wind-generated energy and (2) one of two tax incentives (a) anticipated value-added tax reimbursement, or (b) accelerated depreciation of project-related assets.

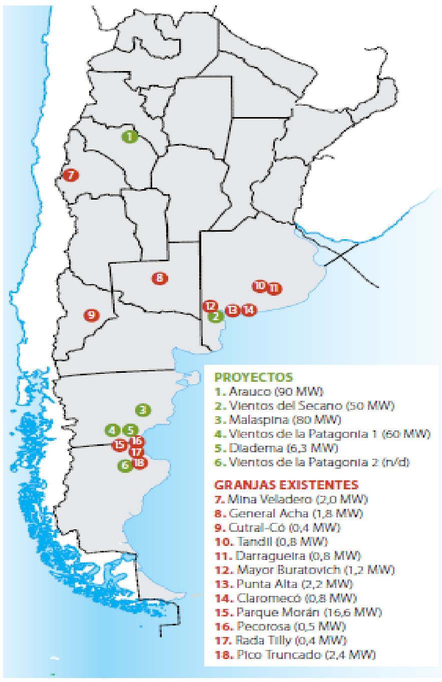
Law #26.190 underscored the political intention of promoting the economy, generating jobs through renewable energy development, and suggesting local governments reduce various local taxes and lower barriers to entry. The law created an initiative called GENREN, which aimed to increase the share of renewable energies to 4 percent of electricity production by 2013 and 8 percent by 2016 by awarding new contracts to the private sector. GENREN included feed-in tariffs for energy production from renewable sources along with incentives such as a 15-year payment plan to help install 1,000 MW of renewable capacities, including 500 MW of eolic power plants.

An additional incentive in the form of an adjustable premium paid to wind energy suppliers as well as the market rate of approximately US$4 per MWh. The premium is to be funded through a Renewable Energy Trust Fund, which is in-turn funded through additional charges to consumers[21].

In 2007, Resolution 220/2007 & 108/2011 built upon Law # 26.190 by guaranteeing 10-year energy contracts with ENARSA to companies supplying new energy projects. In addition, it offered other financial reimbursements from the government in order to maintain equipment, install new equipment, and guarantee an adequate return on investments.

Figure 5, below, shows the existing wind projects along with their MW capacity of existing and projected wind farms.

Figure 5: Wind Farms and Capacity in Argentina



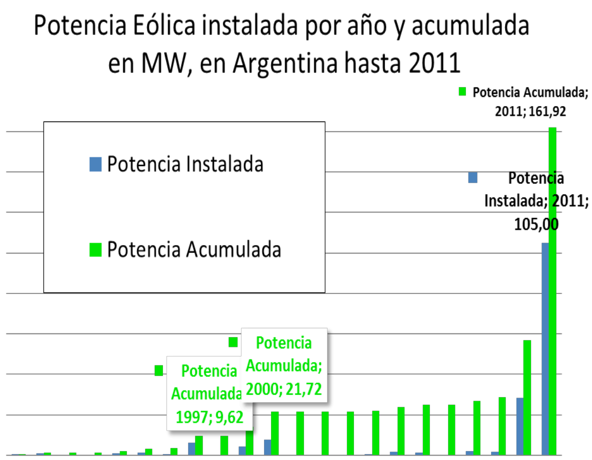

Source: CADER (2009)

When looking at existing wind farms and future projects, it is relevant to look at the progress over time. The chart and graph below show the cumulative MW capacity achieved over time (since 1990) and the MW capacity that has been installed annually.

The data shows that MW capacity since 2010 has more than tripled—this is in part because of the goals set by GENREN and other investor incentives that have become available to new wind power development projects.[22]

[21] Kennedy, 2009, 2.
[22] PowerPoint from Luis Bertanasco, 13 March 2012.

Figures 6 and 7: Installed Wind Capacity, Annual and Accumulated




| AÑO | MW | MW acum. |
|---|---|---|
| **1990** | 0.12 | 0.12 |
| **1991** | 1 | 1.12 |
| **1992** | 0 | 1.12 |
| **1993** | 0 | 1.12 |
| **1994** | 0.9 | 2.02 |
| **1995** | 1.2 | 3.22 |
| **1996** | 0.4 | 3.62 |
| **1997** | 6 | 9.62 |
| **1998** | 0 | 9.62 |
| **1999** | 4.35 | 13.97 |
| **2000** | 7.75 | 21.72 |
| **2001** | 0 | 21.72 |
| **2002** | 0 | 21.72 |
| **2003** | 0 | 21.72 |
| **2004** | 0.2 | 21.92 |
| **2005** | 1.8 | 23.72 |
| **2006** | 1.2 | 24.92 |
| **2007** | 0 | 24.92 |
| **2008** | 2 | 26.92 |
| **2009** | 1.8 | 28.72 |
| **2010** | 28.2 | **56.92** |
| **2011** | 105 | **161.92** |

*Source: Luis Bertanasco, ENARSA*

As the data shows above, there exists massive potential alongside early promotion of renewable energy legislation in Argentina that projects a 2,000 MW capacity. However, despite this, the wind energy sector has only recently begun to develop fully in Argentina. The main reasons for lack of wind power development during the 1990s and 2000s were (1) an abundance of natural gas at low prices, which resulted in technological development and infrastructure centered on natural gas, (2) insufficient economic incentives to promote wind power development, and (3) heavy government subsidization of electricity consumers since 2002.

The government's pricing structure has produced large government deficits that continue to accrue at an unsustainable rate. This, combined with significantly increased demand for electricity, has prevented the true marginal cost of natural gas generation from setting the wholesale price, as customer bills continue to be subsidized by the state. With a significant differential between the spot prices and the marginal costs, the market is not allowed to set the price; therefore, there has been little incentive to invest in the energy sector. Since the government natural gas development incentives fall far short of covering the actual cost of energy development, investors cannot recoup their investments or operating costs [23].

In a 2009 study on Argentina's wind energy industry, CADER also identified additional setbacks for wind power development. The first is the time gap between the creation of the 2006 promotion law, and its late implementation in 2009. The time lag came along with a lack of enforcement, accountability and penalties for failure to achieve the renewables target. The second setback is the insufficient financial incentive to help subsidize the difference between spot price and wind generation cost. If the financial benefits reaped from the environmental impact of wind power were taken into consideration, heavier development

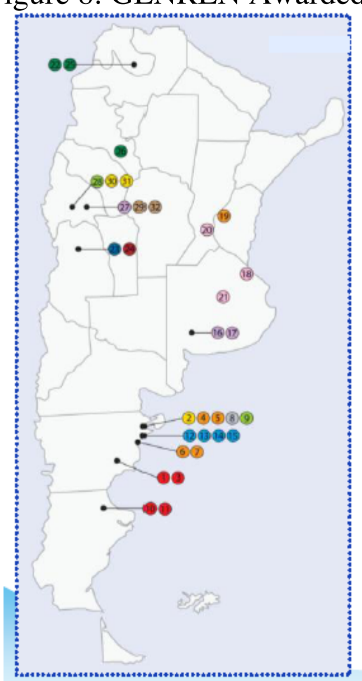
[23] Recalde, 2010,15

subsidies would likely be provided in the wind sector. Additionally, and, as discussed further below, a lack of stability and predictability of public and energy policies in Argentina is a critical detriment for investment. Lastly, also discussed below, limited access to international capital markets, resulting from unresolved issues related to the Argentine IMF default in 2001, makes it difficult to receive investment capital, particularly from foreign sources.[24]

Despite the setbacks over the last twenty years, eolic power sources have developed with great force over the last two years. Severe natural shortages during the winters of 2001-2002 and 2007-2008 forced the Argentina's government to look at alternative energy sources. Argentina's habit of importing electricity and natural gas from neighboring countries (discussed below) despite its vast reserves is unsustainable and the government found itself desperately seeking alternatives.

After various modifications, GENREN has finally begun to bring about change in Argentine energy. Seeking to meet the goal of 8 percent in renewables by 2016, GENREN recently awarded 17 private-sector contracts for construction and supply of wind plants of up to 50 MW capacity totaling 754 MW of wind energy. The contracts guarantee the purchase of energy production for 15 years at average prices of US$126.9/MWh[25]. This price is significantly above the spot price of approximately US$30/MWh[26] and the premiums offered by the 2006 promotion law. Figure 8 shows the geographic distribution and capacity of the awarded wind power projects.

Figure 8: GENREN Awarded Wind Power Projects



EÓLICA (754 MW)

| | Central | Proponente | Potencia MW |
|---|---|---|---|
| 1 | Malaspina I | IMPSA | 50,0 |
| 2 | Pto. Madryn Oeste | Energías Sustentables S.A. | 20,0 |
| 3 | Malaspina II | IMPSA | 30,0 |
| 4 | Pto. Madryn II | Emgasud Renovables S.A. | 50,0 |
| 5 | Pto. Madryn I | Emgasud Renovables S.A. | 50,0 |
| 6 | Rawson I | Emgasud Renovables S.A. | 50,0 |
| 7 | Rawson II | Emgasud Renovables S.A. | 30,0 |
| 8 | Pto. Madryn Sur | Patagonia Wind Energy S.A. | 50,0 |
| 9 | Pto. Madryn Norte | International New Energies S.A. | 50,0 |
| 10 | KOLUEL KAIKE I | IMPSA | 50,0 |
| 11 | KOLUEL KAIKE II | IMPSA | 25,0 |
| 12 | Loma Blanca I | Isolux S.A. | 50,0 |
| 13 | Loma Blanca II | Isolux S.A. | 50,0 |
| 14 | Loma Blanca III | Isolux S.A. | 50,0 |
| 15 | Loma Blanca IV | Isolux S.A. | 50,0 |
| 16 | Tres Picos I Básica | Sogesic S.A. | 49,5 |
| 17 | Tres Picos II Básica | Sogesic S.A. | 49,5 |

Source: ENARSA (2010)

[24] CADER (2009)
[25] ENARSA, 2010,14
[26] CAF,2010, 62

When selecting the contract recipients, GENREN required projects to have a capacity factor between 35 and 45 percent, along with a required return on investment of 14 percent in wind power projects in Argentina. Based on parameters for equipment cost, depreciation, and with marginal costs ranging between US$90-100/MWh[27], CADER has estimated that for a 14 percent return on investment, compensation for wind power is between US$100-130/MWh, in order to attract private sector investment. This estimate is confirmed by the awarded price of US$127/MWh through the GENREN tender, even though the spot market price is approximately US$30/MWh[28].

While this may not appear profitable, CADER's analysis estimates that wind power would be cost-competitive when crude oil prices reach the US$70-95 per barrel level. Given that the current oil price in March 2012 was around US$125, and because natural gas electricity subsidies are unsustainable in the long run, wind technology can be competitive.

**The Key Players in Argentina's Energy Industry**

There are multiple governmental agencies and trade associations that affect the energy industry in Argentina. Within the Ministry of Federal Planning, Public Investment and Service, the Secretariat of Energy is responsible for energy planning. The country's electricity distribution system, Sistema Argentina de Interconexcion (SADI), is run by another government agency, Compañía Administradora del Mercado Mayorista Eléctrico SA (CAMMESA). Created in 2004, Energia Argentina SA (ENARSA) is a government-owned energy company that plans to sell shares in the open market at some point in the near future. ENARSA is the leader in carrying out renewable energy projects. The Argentine Renewable Energies Chamber (CADER) is a private industry trade association established in 2008 to handle matters related to clean energy solutions.[29]

**Argentina's Energy Demand and Supply**

Per capita energy consumption in Argentina has increased annually over the last two decades, with the exception of the economic crisis from 2000-2002 when consumption dropped briefly. Argentina's per capita consumption is the second highest for any nation in Latin America, second only to Venezuela. Figure 9, below, adequately depicts the steady increase in consumption with the drop from 1.7 toe/cap to 1.5 toe/cap from 2001 to 2002 before consumption again began increasing to 1.9 toe/cap by 2009.[30] As Argentina's consumption continues to grow, additional volumes of nationally produced energy will need to be developed in order to constrain overly priced imports of energy.

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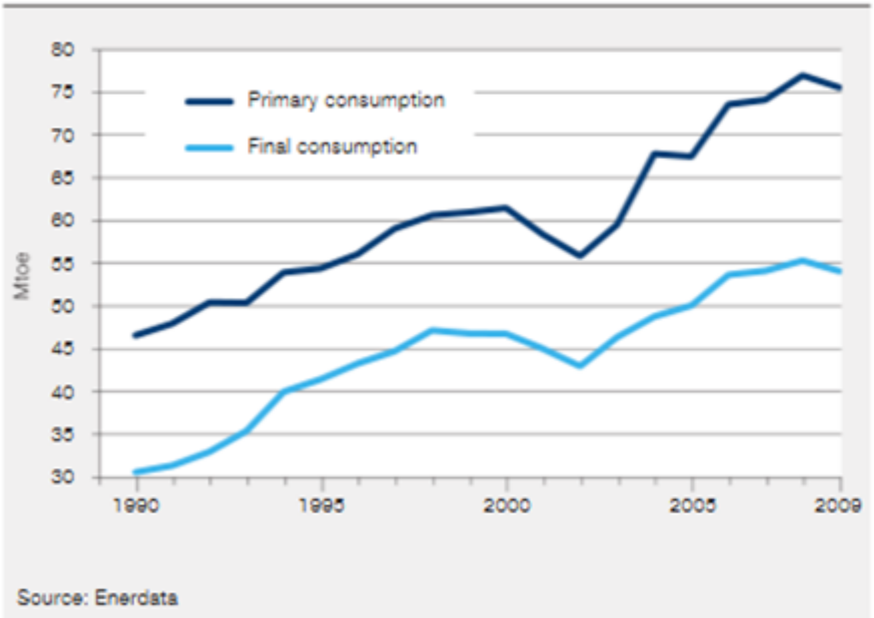
[27] CAMMESA, 2010, 32
[28] CAF, 2010, 45
[29] St. James, Carlos. "Argentina's Energy Framework: Preparing for an Onslaught of Renewable Energy Investment," (*Renewable Energy*, December 2010), 2.
[30] Argentina Efficiency Report, Enerdata, 2011, 2.

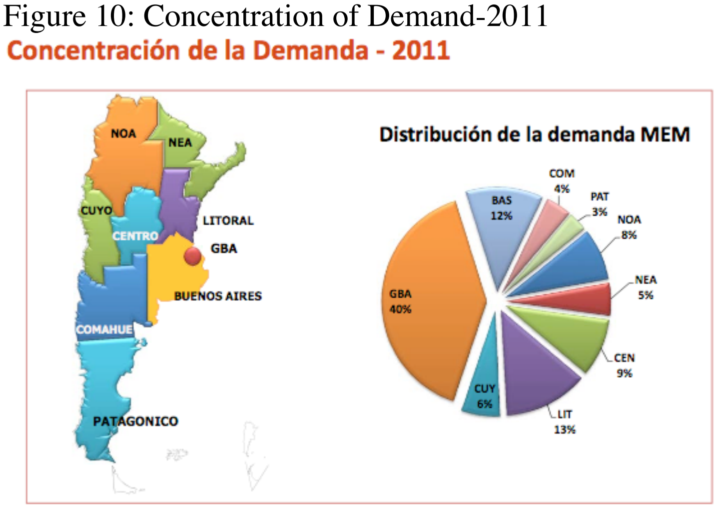
Figure 9: Total Energy Consumption Argentina 1990-2009




## Electricity in Argentina

Due to the outlay of Argentina's population, all roads lead to Buenos Aires, where the majority of demand for electricity is concentrated[31]. As Figure 10 illustrates, the metropolitan area of the City of Buenos Aires constitutes 12 percent of the overall demand while the downtown outskirts, named Gran Buenos Aires, add an additional 40 percent of the entire country's demand for electricity[32].

Figure 10: Concentration of Demand-2011

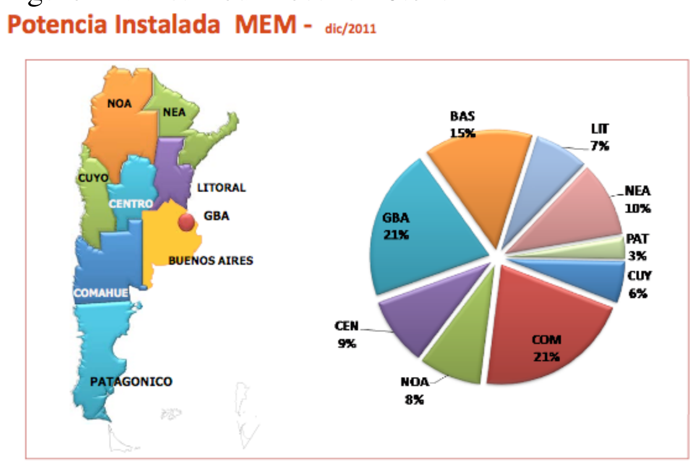



*Source: CAMMESA, February 2012.*

[31] CADER 2009, 15.
[32] CAMMESA, February 2012.

Although the zones of Gran Buenos Aires, Litoral and the metropolitan city of Buenos Aires together make up 65 percent of the national demand for energy, these areas only generate approximately 43 percent of the total electricity for the country[33]. As demonstrated in Figure 11 below, most of the electricity produced in Argentina comes from sources of energy located in very distant regions of the country that are sparsely populated[34]. Because of the tremendous size of the country, vast networks of transmission lines and pipelines have thus been installed that span the entire country in order to supply Buenos Aires with sufficient electricity. It is these existing pipelines that efficiently transfer natural gas that greatly serve the use of SNG in Argentina.

Figure 11: Installed Electric Potential




*Source: CAMMESA, February 2012*

In 2011, according to data provided in an interview with CAMMESA, the total installed capacity of the electricity sector was 29,443 MW. The gross maximum potential was 21,564 MW and the energy demand was 116,418 GWh, or 13,290 MW[35].

### Natural Gas in Argentina

Over the past few decades, natural gas has occupied an increasingly growing portion of the country's overall energy matrix. In 2011, Argentina possessed proven natural gas reserves of 13.4 trillion cubic feet—making the country the third largest holder of the shale gas in the world.

Figure 12 shows the progression of energy generation in Argentina, as calculated by the International Energy Agency and based on data compiled by various types of fuel from 1971 to 2009. Major trends show that the overall matrix has changed from oil as the major source of electricity to natural gas in 1971 to a complete reversal by 2009 with natural gas generating the majority of electricity, while oil is a minority. Hydroelectricity has evolved from being a negligible amount in the 1970s to a clear second largest after natural gas. Nuclear energy has also appeared on the matrix, though it remains a small percentage of the

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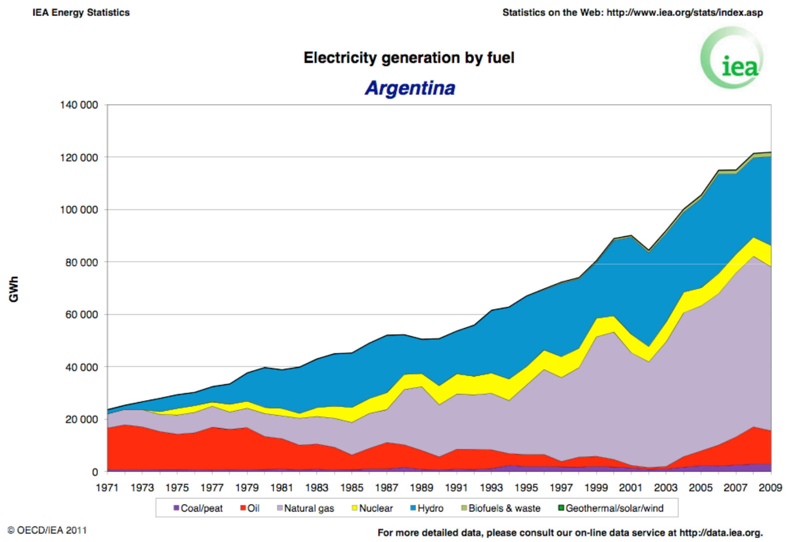
[33] CADER 2009, 15
[34] CAMMESA, February 2012.
[35] CAMMESA, February 2012, 10.

total amount of energy generated. Specifically, in 2009, natural gas comprised 51 percent of the market, oil 36 percent, biomass 4 percent, coal 2 percent and nuclear and hydroelectricity coming together to supply 7 percent.[36]

Figure 12: Electricity Generation by Fuel




*Source: IEA Energy Statistics*

Due to government subsidies that have been in place since 2002, electricity—as has already been mentioned—has been artificially priced far below the marginal generation cost. Since 2004, the spot price for wholesale electricity in Argentina has been determined on the basis of the cost of generation of natural gas at the local price. The marginal cost of electricity produced from natural gas is significantly higher than the calculated spot price because of the use of liquid combustibles and the use of less-efficient generation. About half of the actual production cost is transferred to industrial and individual consumers, with the remainder being subsidized by the Argentine government.[37]

The price of energy, according to Resolution SE 240/03 allows for an unlimited supply of gas, priced at a maximum of US$30/MWh with a monthly average ranging from US$25/MWh-$29.75/MWh.[38] The monomic price, which is a price that includes any additional services and overhead costs due to the sale of combustibles other than natural gas, has an annual average of US$51/MWh. According to national government guidelines, the same price differential policy was applied to end users without any adjustment of tariffs.[39]

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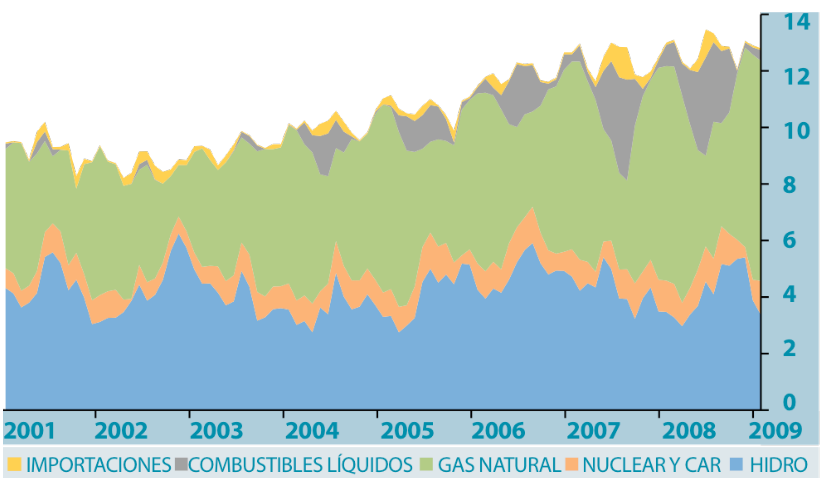
[36] Argentina Efficiency Report (Buenos Aires: Enerdata, 2011), 2.
[37] CADER 2009, 16.
[38] GENREN, 13.
[39] CAMMESA 2010 report, 5.

**Natural Gas Imports**

While Argentina once produced more natural gas than any other country in South America, its production levels have decreased by approximately 10 percent since 2006. The country has been a net importer since 2008, due to the fact that it is South America's largest consumer of natural gas as well. Despite the large quantities of natural gas produced internally, the country is unable to meet the high demand for electricity when it peaks significantly during the winter months of June-September. The winter shortages of natural gas reach as high as 40 percent of demand[40]. Although prices are much higher than gas produced by internal sources, Argentina has to import natural gas from neighboring Bolivia, as well as minimal amounts from Trinidad and Tobago and Qatar, to meet the increased demand that occurs in winter months. Thermal energy is imported from neighboring Brazil and Uruguay during winter as well. The peaks and troughs are a large challenge in providing a consistent supply of electricity from internal sources. Illustrating the high price of imports, in 2008 Argentina spent US$1.8 billion on liquid combustibles and electricity purchased from their neighboring countries in order to generate 7,700 GWh of power—coming to an average cost of US$230 per MWh[41].

Figure 13, below,[42] shows the monthly fluctuation of electricity generation. The figure makes clear the growing percent of liquid combustibles and imported electricity usage during the winter months in recent years.

Figure 13: Electric Generation (in GW) by Type



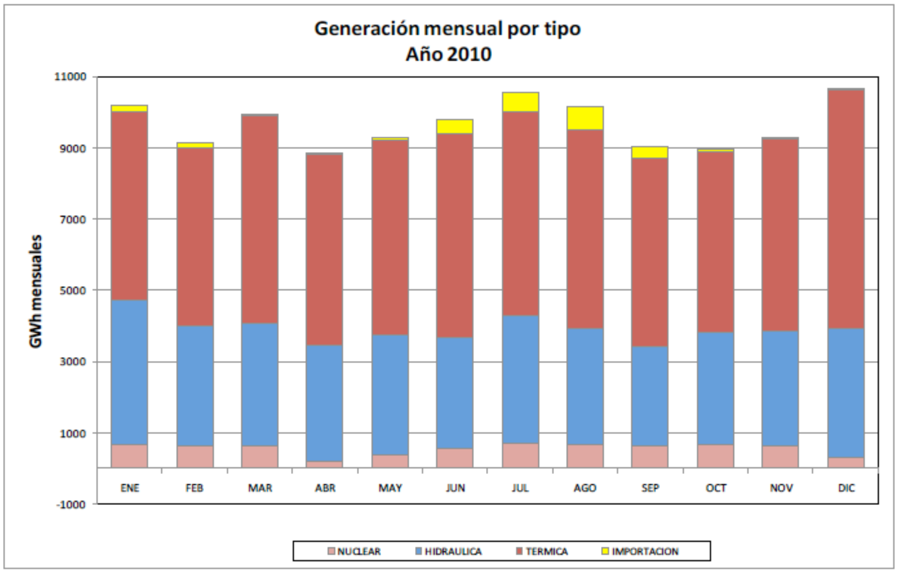

*Source: CADER 2009*

When this is broken down on a monthly basis,[43] Argentina's reliance on imported fuels for electricity generation during the winter months becomes even clearer. While the imports appear to be minimal compared to the overall generation, it is the increase over several years,

[40] EIA Country Analysis Brief, 4.
[41] CADER, 2009, 6.
[42] CADER, 2009, 17.
[43] CAMMESA report 2010, 8.

which makes it more concerning, especially considering the rise in prices of these fuels from neighboring countries.

Figure 14: Monthly Generation by Type—2010




*Source: CAMMESA 2010*

As the demand for natural gas has increased over the past few years, Argentina's government has had to look beyond its borders to find a reliable source. Nearly all of Argentina's natural gas imports come into the country via pipeline from Bolivia. ENARSA has a contract with the Bolivian national oil company through the year 2026, which mandates a current trade volume of 7.7 million cubic meters of natural gas per day. This is expected to grow up to 27.7 million cubic meters per day by the year 2017.

**Existing Natural Gas Pipelines**

Argentina currently has 18,269 miles of natural gas pipeline and planning stages the Gasoducto del Noreste Argentino, which will help connect the remote northeastern provinces of the country to sources of natural gas from both domestic sources and Bolivian imports[44].

Although Argentina has been a net importer of natural gas since 2008, it continues to export natural gas to neighboring countries, primarily Chile, as well as small quantities of gas to Uruguay. In recent years, however, it has become less reliable as a source of natural gas for other countries, due to domestic shortages, which result in supply interruptions of gas to be exported.

Despite high levels of natural gas production, the country is increasingly more reliant on external, more expensive sources. The production of SNG could potentially not only help

[44] EIA Country Analysis Briefs, 6.

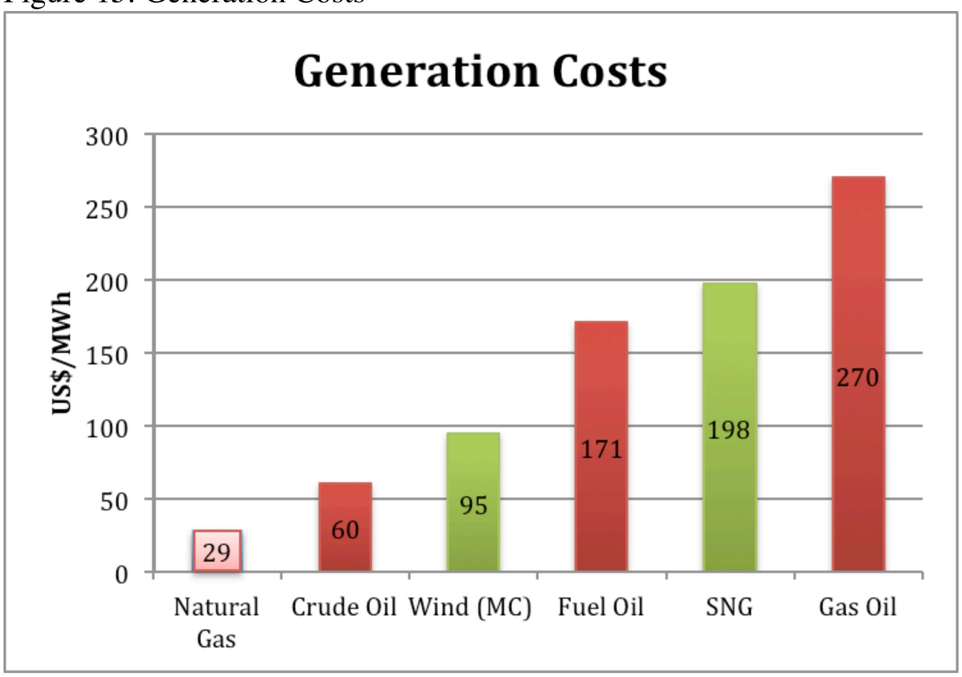
Argentina to address local shortages during periods of increased demand, but would also help the country to be a more reliable exporter of natural gas to neighboring countries.

**Analysis: The Costs, Feasibility and Competition for Implementing SNG Production in Argentina**

Using a model of input and output energy (see Appendix 2 for further detail), it was found that 2.08 $MWh_{el}$ of wind power is needed to produce 1 $MWh_{th}$ of SNG—confirming the 48 percent efficiency of the renewable SNG process using atmospheric $CO_2$ absorption. Given the marginal cost of producing 1 $MWh_{el}$ from eolic sources in Argentina is US$90-$100, the average marginal cost of US$95 MWh was used. Applying the average marginal cost to the input power required to produce 1 $MWh_{th}$ output of SNG yields a price of US$197.6 per MWh.

Figure 15 summarizes the current costs of producing 1 MWh of power in Argentina from varying sources of energy.

Figure 15: Generation Costs




*Source: Author's own calculations and CAMMESA in person interview*

The figure above demonstrates that natural gas and crude oil are by far the cheapest sources of energy. The US$60 per MWh price of crude oil originates from the average price of both WTI and Brent values (US$103 per barrel) for 2011[45]. While crude oil appears relatively cheap, however, the prices of fuel oil and gas oil—of which there is a strong dependence on—illustrate the extreme expenses associated with oil purification. As the price of crude oil increases, so too will other more purified states—allowing SNG production to become more

[45] EIA historical data

competitive. While the figure also illustrates that the cost of renewable SNG is significantly higher than the spot market cost for electricity (US$30 per MWh) and natural gas, several factors must be considered when assessing the viability of SNG:

(1) **Storage capabilities**. The US$198 MWh cost of SNG does not take into account the economic value of the ability to store wind energy. As SNG can be called upon at will to be used as either electricity or as a gas, a tremendous value is created in the ability to more efficiently manage the delicate balance of supply and demand.

(2) **Preexisting, unsustainable subsidies.** Unsustainable government subsidies are not factored into the equation. With extreme subsidies already in existence in Argentina, further study must be conducted that accounts for these values as they can lower the price considerably.

(3) **Carbon credits.** The cost of SNG does not consider the carbon credits that can be applied from the reduction of atmospheric $C0_2$ through the SNG absorption stage. Producing 1 MWh of SNG will effectively require 208.8 kg of $CO_2$. As oxygen is also a byproduct of electrolysis, $O_2$ can also be sold to reduce the overall price.

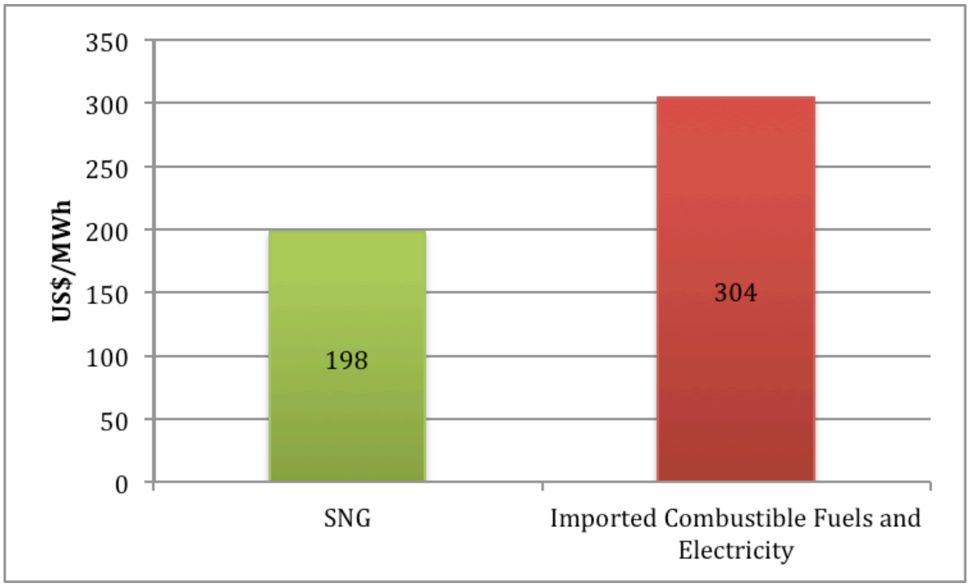
(4) **Carbon dioxide absorption.** It must also be noted that the least efficient method of methanation—atmospheric absorption—is being used in this analysis. Using a biosyngas or direct biogas mixture improves overall efficiency by 15 percent.

(5) **Increase in fossil fuel prices.** As the price of combustible fuels continues to rise—due to increasing over consumption—the price of traditional energy sources will become increasingly less competitive in comparison with alternative energy sources.

Although the generation costs of electricity from domestic natural gas are substantially lower than that of SNG, SNG becomes a very cost effective source of energy when compared to the additional combustible fuels that Argentina must import in order to generate electricity. As mentioned earlier, in 2008 Argentina spent an average of US$230 per MWh for imported liquid combustibles and electricity. Accounting for the spot price variation of “energy” from 2008 to 2010 (See Appendix 3),[46] an equivalent average spot price for 2010 was found to be US$304.43 per MWh. The equivalent figure for 2010 was calculated in order to create a more homogenous comparison. In 2010, Argentina used a total of 2,351 GWh imported from neighboring countries, with 77 percent of these imports consumed during the peak winter months of June through September. As the average price for imported electricity is considerably higher than the price for SNG, Argentina could have saved up to 35 percent by using SNG in place of imports. However, in order to attain the desired 77 percent of total importation of liquid combustible fuels and electricity necessary in winter months, Argentina has to further develop its existing installed wind capacity to attain levels closer to 2,000 MW in production.

[46] CAMMESA 2010.

Figure 16: SNG Cost Comparison to Imports




*Source: Author's own calculations*

Replacing imported energy purchases for domestic SNG production has significant benefits as SNG production is:

(1) **Clean and renewable.** SNG would be produced from a renewable, clean source that also helps remove $CO_2$ from the environment, significantly contributing to environmental preservation.
(2) **Cost-effective**. Domestic production of SNG would be more cost effective than generating the same energy from imported fuels.
(3) **Beneficial for the economy.** Developing the SNG industry would generate a significant amount of permanent domestic jobs, along with areas ripe for private sector investment, helping promote economic development while developing the skills of Argentine workers. This should be particularly appealing when considering the cost of import energy prices, as well as the existing, unsustainable deficit generated by government subsidies in the energy sector.
(4) **Self-sufficient.** Most importantly, Argentina would become energy self-sufficient in the long run, and no longer depend on foreign fuels. In times where traditional resources are in danger of depletion, energy independence is of utmost importance and developing SNG production from interminable eolic sources thus becomes a necessary step in satisfying future energy needs of Argentina.

**Hydrogen Production in Argentina:**

In a first step towards energy independence and renewable energy diversification, Argentina has already begun producing hydrogen from eolic sources. This is important to note as it shows an interest in advancing renewable energy technology, which would allow the country to capitalize on the vast potential of clean energy available from wind. Additionally, the research that has been taking place at the hydrogen test plants directly benefits the production of SNG as the chemical process of making $H_2$ is identical to that of making SNG, but takes the production one step further by adding $CO_2$ to hydrogen to create the SNG, with water as a byproduct. This existing infrastructure could potentially help the country transition more easily, and at lower investment costs, into the production of SNG.

The purpose behind the production of $H_2$ is to purify natural gas blends by adding up to 15 percent $H_2$ to the mixture, but also to develop hydrogen fuel celled vehicles for mass transportation. Currently, the only hydrogen production plant in South America is located in the desolate region of Chubut, Argentina. More than 900 miles from the country's capital, Chubut has a small population of 20,000 inhabitants. Within this isolated city lies the Planta Experimental de Hidrógeno (Experimental Hydrogen Plant).

Taking into account the average marginal cost of wind energy (US$95/MWh), production of 1 $m^3$ of $H_2$ will cost US$0.475. While 1$m^3$ of $H_2$ generated from wind has the same generation price in the Planta Experimental and in SNG production, SNG requires three times the amount of input energy in order to produce 1$m^3$ of SNG. Producing 1$m^3$ of SNG thus will cost $1.96, where about 57 $MJ_{el}$ is needed for electrolysis (including heat losses) and 17 $MJ_{el}$ for $CO_2$ absorption. Although 1$m^3$ of SNG costs about 4 times 1$m^3$ of $H_2$, any addition of more than 15 percent $H_2$ to the natural gas mixture will call for extensive, and costly, changes to the existing infrastructure—most notably, new pipelines will need to be developed as the current pipelines intended for natural gas usage cannot safely incorporate these new $H_2$ levels. Laboratory tests are currently being conducted, however, where the natural gas mixture can contain up to 40 percent $H_2$. While further tests are needed, such a mixture could prove cost effective when taking into account the tremendous amount of investment needed for the necessary infrastructural changes.

Until then, however, SNG production in Argentina should be further developed as the production of hydrogen has challenges and limitations that SNG does not have. Most notable is that SNG can seamlessly fit into the current infrastructure that exists in Argentina—both the extensive natural gas pipelines, as well as the motors of all compressed natural gas vehicles. The production of SNG has an additional environmental benefit of carbon reduction as carbon dioxide is removed from the atmosphere in the final stage of methanation. By implementing the additional step of methanation—which should be relatively cost free as the Experimental Plant already has the majority of the necessary components—Argentina could leverage the existing infrastructure, increase the levels of renewable energy in the country's energy matrix, and become more energy independent as relying on expensive imports of natural gas from neighboring countries during the high demand winter months will no longer be needed.

**An Assessment of the Energy and Investment Climate in Argentina**

Regardless of the type of energy, development requires support from the government, development of policy, investment in infrastructure and financing—and interest—from the private sector, both foreign and domestic. As a result of a convoluted energy subsidy system, inflation and other economic imbalances, development of new renewable energy methods is challenging in Argentina. While the country's abundance of natural resources and underdeveloped energy potential should make Argentina a prime candidate for foreign investment, its government and financial history—the nation has yet to pay off its foreign debt from the 2001 economic crisis—make investors hesitant.

Considering the multiple times Argentina has defaulted on its international debt to the International Monetary Fund and other lenders, attracting private and foreign investment in the energy sector is a challenge. Ambassador Morelli, the Energy & Technology Unit Coordinator of Argentina's Ministry of Foreign Affairs, International Trade and Worship, voiced his concern: "The problem with policy is that you have to find a business cycle that makes it attractive for the private sector to invest. Politics is the issue here in Argentina."[47] Similarly, Carlos St. James, Regional Director and Board Member of Latin American & Caribbean Council on Renewable Energy (LAC-CORE), said, "Argentina is an impossible country to finance."[48]

Attracting private and foreign investment becomes even more cumbersome considering policies and unsustainable energy subsidies under the current government. The Argentine government subsidizes energy prices to unreasonable levels, creating an unrealistic energy market. "The politics of controlled price make the market virtual [unrealistic], because the heavy subsidization throws off the prices. It's a complicated mechanism that does not allow for free competition," said Sebastian Kind, the Director of Aires Renewable Energy Sources, a private energy consulting firm located in Buenos Aires.[49]

Additionally, Ambassador Morelli also stated that the transfer of energy information and technology with other nations could also be a challenge for development of SNG and new energy methods. The Ambassador noted that business cycle and investment, transfer of technology, risk and stability of supply are issues of concern for implementing SNG or any similar new energy process, in Argentina. Additionally, capacity building, or the training of energy workers in the processes, will also be necessary. Lastly, he noted that since the energy subsidies ensure reduced prices on the consumer side, Argentine citizens are more likely to be concerned with stability of supply over price.[50] As SNG production allows for the seasonal storage of electricity, such a method could serve the interests of Argentine consumers.

In spite of the complexities of the Argentine investment climate, Sebastian Kind believes that Argentina is on the verge of becoming a very attractive market for private and foreign investors. He mentioned the particular cases of Germany and China, who are already investing in wind energy in Argentina.

Kind also noted for the last decade, Argentina has devoted much of its renewable efforts in terms of both policy and financing to biofuel development. "In 2000, there was a strong feeling that natural gas was the driver of the nation. Then, due to limitations in supply and

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[47] Ambassador Alfredo Raul Morelli, personal interview, 12 March 2012.
[48] Carlos St. James, personal interview, 13 March 2012.
[49] Sebastian Kind, personal interview, 13 March 2012.
[50] Ambassador Alfredo Raul Morelli, personal interview, 12 March 2012.

stability, industry was growing but it was limited by natural gas. Following regulation, there was a 20-30 percent increase in biofuels over the last decade," he said.[51]

Now, the nation's renewable energy community has set its sight on wind power and the hydrogen that results from electrolysis. "Currently in Argentina, we have people studying the science and production of hydrogen from wind," said Consular Sergio Servin, who works in energy and technology within Argentina's Ministry of Foreign Affairs.[52] At present in Argentina, wind energy development and the exploration of storage capabilities is focused on hydrogen. At present, ENARSA is focused on converting wind energy into storable forms of hydrogen, which is occurring at 30-to-70 percent efficiency. Efforts are also being made in conjunction to develop a hydrogen-friendly motor for vehicles, which is currently in the testing state.[53]

In a meeting, ENARSA employees Luis Bertenasco and Dadour Dadourian expressed hesitation regarding the SNG methanation process, as it requires an additional chemical reaction beyond hydrogen, and intimated their preference for hydrogen in Argentina. Similarly, in a meeting, Constanza Diaz, an engineer in the Energy Department of the Ministry of Planning, expressed her preference for hydrogen over methane, as the process of hydrogen production is more environmentally friendly because it requires a smaller energy input. Energy experts from CAMMESA, the Argentine government's energy regulatory agency, expressed doubts on methanation process, saying that there is a loss of efficiency in the Sabatier method and stating that the competition with hydrogen right now in Argentina is strong. Last but not least, CAMMESA experts expressed concern that the Argentine transportation system cannot store a significant amount of gas, as there is only space for 100 million cubic meters in the aqueducts.[54]

Although several agencies and representatives in Argentina expressed concern with SNG development due to: (1) efficiency losses in the SNG process, (2) the lack of a means for storage of the energy form, and (3) a failure to attract private investment in the country, this paper finds that the renewable SNG production can alleviate said stresses. Responding to these concerns, this study puts forth that the ability to seasonally store a sufficient amount of electricity to stabilize energy supply and demand while reducing the need for importation is bound to attract foreign investment. Exchanges of technology and best practices with other countries, such as Germany, can provide foreign investors with the knowledge to implement this technology elsewhere. As private investment increases, so too will technological advances, increasing the overall efficiency of the process. Lastly, the construction of additional storage units and production plants will create new jobs for the Argentine economy in multiple industries. The combination of these factors—along with a forecasted continuing increase in energy demand and consumption—will generate an entirely new industry that is contingent upon the expansion of the wind industry itself. Such a

[51] Sebastian Kind, personal interview, 13 March 2012.
[52] Sergio Servin, personal interview 12 March 2012.
[53] Luis Bertanasco and Dadour Dadourian, personal interviews, 13 March 2012.
[54] Sabina Mastrangelo, Ing. Daniel Geler, Ing. Jose Maria Rodriguez, Ing. Mariela Beljanksy, personal interviews, 16 March 2012.

combination will lead to a tremendous opportunity for job creation and capacity building as each project requires a significant amount of localized labor.

**Discussion**

After analyzing the existing infrastructure, the required investment, politics and policies affecting the development of SNG in Argentina, it becomes apparent that Argentina's electricity and natural gas systems are extremely complex and in need of adjustment. However, despite the challenges affecting Argentina's energy future, this paper aims to detail why SNG is a beneficial form of energy, why SNG production will benefit Argentina, and why SNG production should be implemented in Argentina in a timely fashion

As discussed, the authors of this study, in partnership with the Inter-American Development Bank, selected SNG as an ideal form of energy because it is (1) clean, (2) renewable, and (3) provides a storage medium, which is lacking in forms of clean and renewable energy such as wind and solar.

Argentina was selected as the ideal candidate for this study because the nation (1) possesses significant natural gas reserves and the corresponding infrastructure and vehicles, (2) has a high wind capacity and potential above the necessary efficiency, and (3) is currently working in-depth with hydrogen, which is only one chemical reaction away from SNG.

One of the important features that makes Argentina an ideal candidate for implementation of SNG is the nature of its energy matrix—where the vast majority of electricity and natural gas production occurs at vast distances from the capital—thereby leading to the development of a well-developed network of natural gas pipelines and electricity infrastructure along with public transportation— such as taxis— that operates off of natural gas. Additionally, as is discussed in-depth in this paper, Argentina is currently working and experimenting extensively with hydrogen production.

Following extensive research, this study determined that SNG production would benefit Argentina in three key ways by helping the nation deal with current major economic and energy challenges. The implementation of SNG production in Argentina will benefit the nation by (1) removing the country's current dependency on energy imports and helping stabilize energy supply, (2) creating jobs, building worker capacity and spurring economic growth, and (3) helping the nation deal with the projected increases in its already high energy consumption.

While the country is the third largest holder of natural gas reserves, the nation still relies heavily on natural gas imports. While in the short run these complexities drive the status quo, in the long run the current system is unsustainable. Looking at Argentina's current electric capacity, we find that the country does maintain an installed electric capacity that is greater than the country's current demand for energy; however, it struggles to manage ebbs and flows in energy demand, which continues to increase. As illustrated in an interview with CAMMESA, Argentina's maximum installed capacity is 21,564 MW, while the maximum demand is 13,290 MW. The surplus in energy, however, is not enough to cover the vast differences between peaks and troughs seen especially in the winter months—and as a result Argentina must import natural gas, electricity, and liquid combustibles from various countries—as discussed earlier in this paper.

In addition to affecting energy supply, the need to import electricity hinders the country by minimizing its energy self-sufficiency and causing the country to be beholden to foreign nations and the politics that come along with them. With international politics always in flux, it is politically wise for Argentina to focus on a more secure energy future—one with reduced imports and greater energy independence

In addition to politics and energy security, the importation of energy is detrimental to the Argentine economy—with money flowing out of the country and into the hands of foreign companies and workers. Moreover, as the price of fuels and commodities continue to rise, the unsustainability of the situation becomes even more apparent. With a large current account deficit already in place driven by the insurmountable energy subsidies paid by the state, the deficit can only be expected to increase as the reliance and price of foreign combustible fuels rises.

Furthering development and attracting investment to alternative and renewable energy sources is thus becoming imperative for Argentina's energy independence. Wind energy has already been proven to be competitive when oil is priced above US$90 per barrel. With today's oil prices significantly above US$100 per barrel, further investment in eolic energy development should be implemented. Furthermore, the high costs associated with importing liquid combustible fuels and electricity illustrate that Argentina is not maximizing profitability since SNG production is available at a lower cost. In addition to benefiting from future cost competitiveness, wind power in Argentina is also highly efficient, with more than 70 percent of Argentine territory operating at equal to or above 35 percent capacity, the benchmark for efficiency. With efficiencies greater than 45 percent (of which Argentina possesses en mass), the cost of power generation can be reduced. Thus, further development of wind power can lead to a reduction in the generation cost of SNG.

By increasing domestic energy production, the nation will hire and train more of its own citizens with the creation of additional wind plants and SNG production centers. This will spur the economy, employ more Argentines, and provide workers with new skills, thereby building capacity.

Lastly, Argentina should implement SNG production to deal with its ever-increasing consumption. As discussed in-depth earlier in this study, Argentina is the second-highest consumer of energy in Latin America and demand will continue to increase.

Moreover, time is of the essence. Argentina should move toward SNG production sooner rather than later—capitalizing upon current renewable energy programs put forth by the government while the political momentum still exists.

Change in Argentina is extremely difficult—especially in a country where policy adjustments are often made with little consideration to previous international arrangements.

Fortunately, the last few years have seen vast improvement—especially related to the development of renewable energy with programs such as the aforementioned GENREN. These new laws, and their enforcement, have moved the country in a positive direction, and illustrate not only a desire, but also a necessity for renewable energy development. In order to move closer to its projected goal of 8 percent of energy from renewable sources by 2016, Argentina should apply GENREN's existing promotional policies to SNG, which will help minimize the gap between the cost of production and the spot price and make SNG more cost competitive. This option becomes particularly relevant if the future political atmosphere in Argentina does not allow for the replacement of imports with SNG production.

While this study has created a basic cost model for SNG production, the true value of SNG has yet to be determined. As such, additional study should be conducted to analyze the specific economic value of storing and reconverting a fluctuating source of energy —in the form of bidirectional SNG power—for an entire season.

Argentina must invest in the production of SNG to serve as an addition to and substitute for traditional combustible fuels and to deal with its energy, economic and political challenges. Therefore, this study, following thorough research and analysis, offers the following recommendations:

**Recommendations**

(1) Argentina should implement the singular additional methanation step to the current production of hydrogen in order to begin producing SNG, as SNG does not require the costly change in infrastructure and vehicular compatibility that would otherwise be necessary.
(2) Argentina should use domestic SNG production as a means to slowly replace the importation of liquid combustible fuels and electricity. As these fuels continue to be overly consumed and demanded—both domestically and internationally—their prices will undeniably increase. This paper has quantifiably shown that such a replacement has economic and political gains. Argentina should conduct further study that analyzes the specific economic value of storing and reconverting a fluctuating source of energy—in the form of bidirectional SNG power—for an entire season.
(3) Lastly, Argentina should analyze the cost of SNG generation in more precise detail. Such a study should incorporate the specific consumption rate (in kcal/kWh) and the calorific value of SNG. Such an analysis was not conducted in this study because the rate of specific consumption of SNG is not currently available. With time and further development, however, such values should become known. An analysis with these values will create a more homogenous comparison between generation costs across various sources of energy.

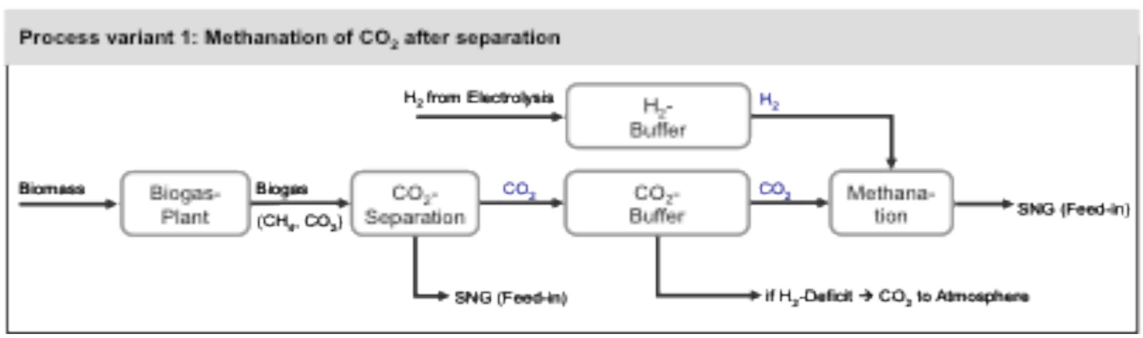
## Appendices

### Appendix 1: SNG Efficiencies

Through electrolysis, water is decomposed into hydrogen and oxygen, typically using a caustic potassium hydroxide (KOH) solution at temperatures of 70-140°C.[55] Such electrolyzers work at pressures of 1-200 bar and are available at capacities less than 0.1 $MW_{el}$.

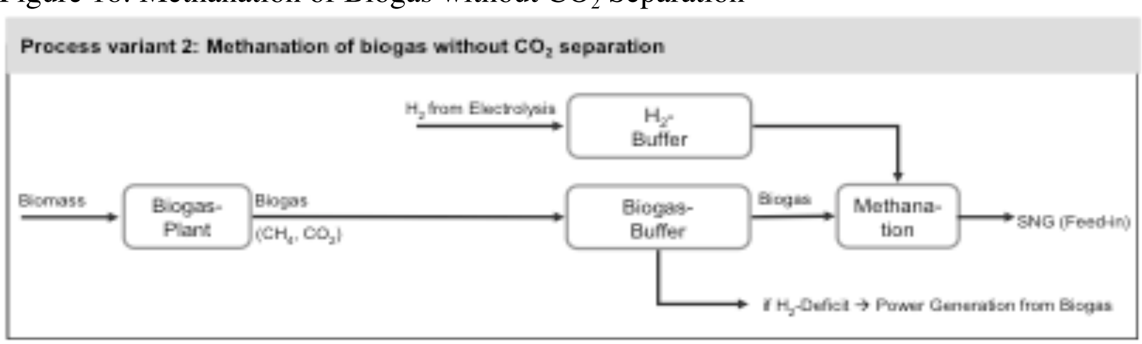
According to the ZSW method, there are three main ways to produce SNG via methanation. The first, biogas to SNG, occurs through an anaerobic fermentation process where biogas is transformed into $CH_4$ and $CO_2$—the resulting solution will also contain minor components of $H_2S$, $NH_3$, and $N_2$, and $O_2$.[56] The biogas is then turned into biomethane through the removal of the $CO_2$ ($CO_2$ separation), water vapor, and any additional components. $CO_2$ is thus produced as an "off gas" of the biogas to biomethane conversion. This "off gassed" $CO_2$–which is not associated with climate-relevant emissions—is now available to be combined with the $H_2$ created through electrolysis. Alternatively, as Specht illustrates in Figure 17, the $CO_2$ from biogas can also be used directly, without previous separation, by feeding the entire biogas stream directly to a methanation unit.[57]

Figure 17: Methanation of $CO_2$ After Separation




*Source: Michael Specht and Michael Sterner*

Figure 18: Methanation of Biogas without $CO_2$ Separation




*Source: Michael Specht and Michael Sterner*

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[55] Specht, 8.
[56] Ibid.
[57] Specht, 11.

If a solid fuel is gasified rather than burned, a combustible producer gas is formed that reacts with air, oxygen, and/or steam—thereby producing the required raw input gas. While its composition depends on the gasification method of the biomass, ideally the main components include $H_2$, CO, $CO_2$, $H_2O$, and—depending on the gasification method—$CH_4$.[58] The feed-in biogas is then cleaned of all other minor components (most likely sulfur compounds, ammonia, and tars) and is passed through the Absorption Enhanced Reforming process developed at ZSW. In this process the CO and $CO_2$ are converted to methane (Equations 1-3) via the hydrogen already present in the gas.[59] Since the Absorption Enhanced Reforming process adjusts the $H_2$ present in the gasified biomethane due to configurable stoichiometry, no further (separation) steps are necessary other than separating the reaction water.[60] However, Specht also states, "[the] addition of $H_2$ to the gasification gas allows virtually complete conversion of the biogenic carbon to fuel carbon."[61] Thus, adding hydrogen produced via electrolysis from eolic (wind) sources will significantly improve the overall efficiency of biosyngas methanation. According to Sterner, current methanation from a biosyngas with the main components being $H_2$, CO, and $CO_2$ has an efficiency of approximately 75-85 percent.[62]

Recovering $CO_2$ from the atmosphere reduces SNG generation efficiency by approximately 15 percent down to 48 percent. As Sterner states, "Generating 10 $MJ_{th}$ (0.28$m^3$) of [SNG] requires 16 $MJ_{el}$ for electrolysis including thermal energy losses of the methanation (mean efficiency 63 percent) and about 4.8 $MJ_{el}$ for CO2 recovery to extract 0.29 $m^3$ (0.58 kg) of $CO_2$."[63] He furthers this by stating, "reconverted into power, the overall power storage efficiency is then about 30 percent."[64] Although a pure $CO_2$ methanation is not yet state-of-the-art, preliminary laboratory tests show rates of up to 95 percent at a pressure of 6-7 bars and at a temperature of 280°C.[65]

**Appendix 2: Pricing SNG**

The generation cost of renewable SNG was calculated using the following formula:

$$16\ MJ_{el} + 4.8\ MJ_{el} = 10\ MJ_{th\text{-}SNG}$$

where 16 $MJ_{el}$ applies to the input energy needed for electrolysis, 4.8 $MJ_{el}$ applies to the energy needed for carbon dioxide absorption from the atmosphere, and 10 $MJ_{th\text{-}SNG}$ refers to the thermal energy created at the end of the reaction. Summing the two input energies shows that 20.8 $MJ_{el}$ is the total input energy required to produce 10$MJ_{th\text{-}SNG}$ (0.28$m^3_{th\text{-}SNG}$). Converting MJ to MWh, 2.08 $MWh_{el}$ of wind power is needed to produce 1 $MWh_{th}$ of SNG—confirming the 48 percent efficiency of the renewable SNG process using

[58] Specht, 11.
[59] Specht, 9.
[60] Ibid.
[61] Specht, 11.
[62] Specht, 8.
[63] Sterner, 110.
[64] Ibid.
[65] Sterner, 109.

atmospheric $CO_2$ absorption. Given the marginal cost of producing 1 $MWh_{el}$ from eolic sources in Argentina is US$90-$100, the average marginal cost of US$95 MWh will be used. Applying the average marginal cost to the input power required to produce 1 $MWh_{th}$ of SNG yields a price of US$197.6 per MWh.

## Appendix 3: SNG Analysis to Imports

As most data used in the analysis section corresponded to values in 2010, the average import price of US$230 per MWh in 2008 was converted to an equivalent 2010 value. This was done by calculating the percentage increase of the spot price of "energy"—as defined by CAMMESA in their 2010 report—and applying this same percentage increase to the 2008 value for imported liquid combustibles and electricity. With a 32.36 percent increase, the 2010 equivalent was found to be US$304.43 per MWh. While this value is not completely accurate as it is merely an extrapolation, this "equivalent" value allows for a more homogenous comparison of data. If the 2008 average price of US$230 per MWh is used as a comparison instead, SNG is still competitive as the Argentine government will still be paying substantially more (US$32.4 per MWh) to create electricity from imported energy sources.

In 2010, Argentina used a total of 2,351 GWh imported from neighboring countries, with 1,827 GWh—or 77.7 percent—being consumed during the peak winter months of June-September.[66] If the cost of US$304 per MWh is applied to the 2,351 GWh imported, this implies Argentina effectively spent US$715 million to satisfy their energy deficit for the entire year and US$556 million in the four winter months alone. Replacing these imports with domestically produced SNG could reduce the price paid by 35 percent. Considering the current potential for eolic capacity in Argentina is at least 2000 MW, a savings of 35 percent could be attained, as the production of 1,827 GWh of SNG would cost US$361 million while the production of 2351 GWh would cost US$464 million at a cost of US$95 per MWh.

## Appendix 4: Hydrogen Production

The Planta Experimental de Hidrógeno is capable of producing 1 $Nm^3$/h of Hydrogen from the consumption of 5 kW of wind energy and 0.9 l/h of water, with a byproduct of 1 $Nm^3$/h of Oxygen (ENARSA). The plant is currently able to store 4.3 $Nm^3$ of $H_2$ and 2.15 $Nm^3$ of $O_2$ at a time, with the oxygen byproduct being sold to hospitals.

It was found that SNG uses 3.17 times the amount of input energy in order to create enough $H_2$ for 1$m^3$ of SNG than the input energy levels needed to create 1$m^3$ of $H_2$. This value was calculated by comparing each input energy level with their output values. 1$m^3$ of $H_2$ requires 0.005 MWh while 1m3 of SNG requires 0.0158 MWh for the electrolysis stage.

[66] CAMMESA 2010

## Works Cited


Ambassador Alfredo Raul Morelli, personal interview, 12 March 2012.

Bertanasco, Luis and Dadour Dadourian. Personal interviews. 13 March 2012.

CAMMESA. Annual Report. Buenos Aires, Argentina. 2010.

CAMMESA. “Jornada Introductoria: Conocimiento del Mercado Eléctrico Mayorista.” Buenos Aires, Argentina. 2 February 2012.

Chandel, Munish et al. “Synthetic Natural Gas (SNG): Technology, Environmental Implications, and Economics.” Durham, North Carolina: Duke University Press, January 2009.

Country Reports: Argentina Efficiency Report. Enerdata, February 2011.

Fernandez, Omar, Sebastian Kind and Mauro Soares. Estudio de la Industria Eolica en Argentina. 2009.

The Inter-American Development Bank Website, http://www.iadb.org/en/about-us/about-the- inter-american-development-bank,5995.html

Kind, Sebastian. Personal interview. 13 March 2012.

Mastrangelo, Sabina and Ing. Daniel Geler, Ing. Jose Maria Rodriguez, Ing. Mariela Beljanksy. Personal interviews. 16 March 2012.

Mercados Energeticos Consultores. Technical Report, An Evaluation of Financing for the Selected Projects.” Buenos Aires: GENREN, December 2010.

PowerPoint from Luis Bertanasco, 13 March 2012.

Servin, Sergio. Personal interview. 12 March 2012.

Specht, Michael, U. Zuberbuhler, F Bamart, B. Fiegl, V. Frick, B. Stumer, M. Sterner and G. Walstein. “Storing Renewable Energy in the Natural Gas Grid: Methane via Power-to- Gas: A Renewable Fuel for Mobility.” Germany.

Sterner, Michael. “Bioenergy and Renewable Power Methane in Integrated 100% Renewable Energy Systems.” Kassel, Germany: Kassel University Press, 2009.

St. James, Carlos. “Argentina’s Energy Framework: Preparing for an Onslaught of Renewable Energy Investment.” *Renewable Energy*, December 2010.

St. James, Carlos. Personal interview. 13 March 2012.

U.S. Energy Information Administration. Country Analysis Brief. Washington, D.C. 2012. http://www.eia.gov/