NEW TECHNICAL AND ECONOMIC SOLUTIONS FOR GAS EXPLOITATION IN THE AMAZON REGION (PERU-BRAZIL PIPELINE)

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ABSTRACT
The Amazon region has been demonstrating a great oil and gas potential in Brazil and in the neighboring countries, specially the field of Camisea in Peru. However, the development of feasible and economically justifiable transport systems, that can allow the flow of those resources to their potential markets, continues to be the great challenge. In this work, we present some options that can be transformed into competitive and commercial projects. We describe different gas pipeline options, discussing their technical, economic and commercial aspects.

1. INTRODUCTION
The Amazon region is a very large area, distributed over more than five countries, and characterized by very low demographic occupation and delicate ecosystems. Those characteristics impose great difficulties upon the energy industry to fulfill the energy needs of the local population. The electric systems are isolated and far from the main national electricity grids. In many cases, those isolated systems are also very obsolete and inefficient, with the predominance of thermopower generation based on expensive and unreliable fuel oil or diesel oil supply.

Some major Brazilian Federal states overlay the Amazon region, for example, the states of Amazonas, Acre and Rondonia, present great unfulfilled energy demands. The lack of investments in the electricity sector and the absence of cheaper local energy sources have always been seen as huge obstacles for the regional development.

Nevertheless, the recent discoveries of large oil and natural gas fields all over the Amazon region and across the different countries have triggered important short-term transformation in the energy generation perspective for the area, with increasing interest particularly in natural gas. This energy option has been attracting governments and investors. The relatively lower capital cost of gas-fired power plants as compared to the hydroelectric systems that can still be developed in the region is a significant positive aspect. For example, while the investment of gas-fired power plants can be as low as US$ 500/kW, the investment cost of some of the cheapest hydroelectric plants planned for the Brazilian Amazon region can reach more than US$ 1200/kW (1). In addition, gas-fired power plants can be built faster, approximately 2 to 3 years as compared to the 8 to 12 years needed in a hydroelectric project, usually located in very wild environment, which will still require major investments in transmission lines.

The natural gas is also much more competitive when compared with the current diesel or fuel oil power generation. The electricity generation cost in the Brazilian Amazon region can be as high as 100 to 150 US$/MWh. This enormous energy cost inhibits the regional economic growth and development. By introducing gas-fired power plants, the regional generation cost could decline to about 30 to 40 US$/MWh. In this context, the development of indigenous natural gas resources and its penetration into the local markets would represent a tremendous energy cost reduction for final consumers or governments that very often must pay for those extra costs through subsidies.

The major difficulty regarding the use of domestic natural gas in the Amazon local energy markets is the distance that usually separates the gas fields from the main cities where the market is concentrated. Those distances are covered by
Amazon forest that raises important economic and environmental constraints.

In this work, we suggest gas pipeline options that could deliver, in a competitive way, natural gas from the large Peruvian Camisea field to the Brazilian Northern and Midwestern energy markets, aiming primarily at using this gas for local power generation. Those projects can guarantee the future offer of natural gas in the Brazilian Amazon region. It can also be an important factor for energy diversification and integration between Brazil and Peru. With such a large project, Brazil and Peru would certainly amplify significantly the economic activity in the region.

We propose different transportation options for linking Camisea's gas to Brazilian energy markets through a transnational pipeline with the following alternative routes:

- Alternative 1: “Pipeline Camisea - Porto Velho”.
- Alternative 2: “Pipeline Camisea - Porto Velho – Manaus”.
- Alternative 3: “Pipeline Camisea - Porto Velho – Cáceres”.
- Alternative 4: “Pipeline Camisea - Porto Velho – Manaus” and “Porto Velho – Cáceres”.

For each alternative, we describe the route, the distances involved, the maximum gas flow forecasted, the pipeline diameter, the operation pressures and the requested compression stations.

2. METHODOLOGY

The following methodology was adopted:

In Section 3.1, we characterized the potential gas supply from the Camisea field. Then, in Section 3.2, we determined the potential demand of natural gas in the Brazilian states of Acre, Rondônia, Manaus and Mato Grosso up to the year 2020. We forecasted those figures by considering the present fuel oil and diesel oil consumption for electricity generation and industrial uses in those states and evaluated the potential for immediate energy substitution by natural gas. We also projected the supply and demand of fuel oil and diesel oil in those same states for the year 2020, considering again the electricity sector as well as the industrial sector (2) and forecasted the future projections for the necessary natural gas to fulfill the same energy demand.

In Section 3.3, we selected and described the pipeline routes. The routes were selected using physical and political maps and satellite images. We took into consideration the following aspects:

- Smaller viable length; considering the topography of the area.
- The need to cross near to the potential consumption centers.
- The need to follow parallel to the existent highways.
- Deviations from preserved and flood areas.

We calculated the pipelines, considering their ultimate gas flows by the year 2020. We adopted typical Bernoulli equation relating the variations of pressure with other variables such as the gas temperature, internal diameter of the pipeline, specific gravity, the length of the pipeline, friction factor and flow. A computer program, as well as the ABNT, ANSI/ASME standards (3) was used, allowing the accomplishment of several simulations.

The pipeline diameter as well as the number of compression stations can be combined in different ways. Therefore the alternatives presented in the present study are not the only possible solution and can be optimized by further analysis. For the different simulations we took the following calculation premises:

a) Flows: The pipelines were calculate to satisfy the maximum demand that will be flowing by the year 2020, taking into account the maximum daily demand of natural gas. It is assumed that the hourly variations can be absorbed by a volume accommodation.

b) Pressure and compression stations: We assumed a 100 Kg/cm² (1,500 psig) discharge pressure in the compressors and a 70 Kg/cm² (1,000 psig) suction pressure in the compressors. The pressure of available gas in the processing plant at Camisea is approximately 70 Kg/cm² (1,000 psig)(4). Therefore, we assumed that the gas producers will have to increase the pressure at Camisea and deliver the gas to the pipeline at 100 Kg/cm² (1,500 psig). It is important to notice that these values were only considered in order to analyze and compare the alternatives. The final value to adopt in each definitive project will depend upon a further optimization process not developed in this paper.

c) Other general parameters:

- Temperature : constant at 20°C
- Elevation: 600 m
- Relative density assumed for the natural gas: 0.6
- Discharge pressure in the compressors: 100 Kg/cm² (1,500 psig)
• Suction pressure in the compressors: 70 Kg/cm² (1,000 psig)
• Minimum operation pressure for the whole system is of 70 Kg/cm² (1,000 psig).
• Industrial Capacity Factor: 0.85
• Electricity Generation Capacity Factor: 0.85
• Pipeline cost: 19.00 US$ / (inches (diameter) x meter)

Eventually, we developed in Section 3.4 the assessment of economic viability. The concept of "net back value" in the field was applied.

First, we calculate the price of competitive fuels in the market, with reference to its caloric equivalence (see table 1). Then we subtract the cost of the transportation tariff.

The Net Back Value in the field is the cost of the fuel oil minus the transport price. This value let us determine the viability of the project (for this we compared the cost of natural gas in Camisea field with the Net Back Value that was calculated).

We used a price of fuel oil equal to 3.01 US$/MMBtu in Porto Velho and Manaus, because fuel oil is much more economic in those areas. In Caceres, we considered the Bolivian gas as the most competitive fuel that Peruvian gas must substitute. The price of the Bolivian gas was estimated at 2.60 US$/MMBtu.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Price of substitute fuels (with reference to its caloric equivalence)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>US$/MMBtu</td>
</tr>
<tr>
<td>Diesel oil</td>
<td>7.16</td>
</tr>
<tr>
<td>Fuel Oil (BTE IB)</td>
<td>3.70</td>
</tr>
<tr>
<td>Fuel Oil (ATE 1)</td>
<td>3.01</td>
</tr>
</tbody>
</table>

The transportation tariff was calculated by cash flow considering a 20 years period, including taxation (33%), depreciation (5 %) and a discount rate equal to 13.46%. The discount rate corresponds to a particular financial scenario, being calculated through the “Capital Asset Price Model” (CAPM) and Weighted average cost of capital (Rwacc=13.46%), which is a widely accepted methodology for financial analysis of new investment projects. By this methodology, we take into account important parameters such as the risk of particular business (Company Beta = 0.8), Risk-free rate (Rfree = 10.22%), Market rate (Rm = 17.22%), Market-risk premium ( Rm-Rfree=7%)

In the financing of major projects such as large natural gas pipelines, where there usually exists pre-established commercial contracts that diminish the risk level of the project, it is possible to consider a degree of external financing up to 70%. By assuming this hypothesis for the several route alternatives, we compared those projects with a discount rate equivalent to 13.46% (weighted average cost of capital).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Discount Rate Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debt/capital ratio</td>
<td>Discount Rate</td>
</tr>
<tr>
<td>70/30</td>
<td>13.46%</td>
</tr>
</tbody>
</table>

3. RESULTS

3.1. POTENTIAL GAS SUPPLY AT CAMISEA FIELD:

In 1984, in the Camisea River, in the Department of Cusco, South Jungle of Peru (about 260 Km Northwest to the city of Cusco), important natural gas resources were discovered. The existing reserves exceed by far any available local demand in Peru. Therefore, the development of Camisea field depends upon finding exporting markets for that gas. Given the distance from any other major market in Peru and/or Brazil, we understand that the most suitable markets for the Peruvian gas would likely be located in the North and Midwest areas of Brazil. The gas volume in place is estimated at about 470 Billion m3. The Peruvian local consumption would absorb in the first year not more than 2.5 million m3/day and, by the year 2020, consumption can reach approximately 18 million m3/day (4). The natural gas demand in the Southeast and Central markets in Peru is mainly focused on electricity generation as well as some industry and mining activity. Therefore, considerable amounts of Peruvian gas could be exported to neighboring countries; primarily to Brazil, where its Amazon Federal states need greater and more reliable energy supply.

3.2. PROJECTIONS FOR NATURAL GAS DEMAND IN ACRE (RIO BRANCO), RONDONIA (PORTO VELHO), MATO GROSSO (CACERES) AND AMAZONAS (MANAUS)

In the table 3, we show the results of our forecasting or natural gas demand in the industrial and electricity sectors in four major Brazilian Amazon states. We observe that, by the year 2020, around 4.97 MMm³/day will be needed in Acre-Rondonia; 5.38 MMm³/day can be used in Amazonas and 8.18
MMm³/day would be consumed in Mato Grosso, totaling therefore approximately 18.5 MMm³/day.

### Table 3
Total natural gas demand (electricity and industrial sectors) - (In Million m³/day)

<table>
<thead>
<tr>
<th>Year</th>
<th>Rondonia</th>
<th>Acre</th>
<th>Amazonas</th>
<th>Mato Grosso</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>0.59</td>
<td>0.22</td>
<td>1.22</td>
<td>2.56</td>
<td>4.09</td>
</tr>
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<td>1999</td>
<td>0.24</td>
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<td>1.40</td>
<td>2.82</td>
<td>4.50</td>
</tr>
<tr>
<td>2000</td>
<td>0.80</td>
<td>0.00</td>
<td>1.60</td>
<td>2.72</td>
<td>5.12</td>
</tr>
<tr>
<td>2001</td>
<td>1.00</td>
<td>0.00</td>
<td>1.79</td>
<td>2.89</td>
<td>5.69</td>
</tr>
<tr>
<td>2002</td>
<td>1.22</td>
<td>0.00</td>
<td>1.99</td>
<td>2.90</td>
<td>5.99</td>
</tr>
<tr>
<td>2003</td>
<td>1.46</td>
<td>0.00</td>
<td>2.20</td>
<td>3.18</td>
<td>6.44</td>
</tr>
<tr>
<td>2004</td>
<td>1.71</td>
<td>0.01</td>
<td>2.41</td>
<td>3.60</td>
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<td>2005</td>
<td>2.01</td>
<td>0.01</td>
<td>2.66</td>
<td>3.99</td>
<td>8.66</td>
</tr>
<tr>
<td>2006</td>
<td>2.24</td>
<td>0.01</td>
<td>2.91</td>
<td>4.34</td>
<td>9.50</td>
</tr>
<tr>
<td>2007</td>
<td>2.26</td>
<td>0.01</td>
<td>2.95</td>
<td>4.44</td>
<td>9.66</td>
</tr>
<tr>
<td>2008</td>
<td>2.47</td>
<td>0.01</td>
<td>3.14</td>
<td>4.73</td>
<td>10.34</td>
</tr>
<tr>
<td>2009</td>
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<td>0.01</td>
<td>3.33</td>
<td>5.02</td>
<td>11.02</td>
</tr>
<tr>
<td>2010</td>
<td>2.88</td>
<td>0.01</td>
<td>3.51</td>
<td>5.30</td>
<td>11.71</td>
</tr>
<tr>
<td>2011</td>
<td>3.09</td>
<td>0.01</td>
<td>3.70</td>
<td>5.59</td>
<td>12.39</td>
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<tr>
<td>2012</td>
<td>3.30</td>
<td>0.01</td>
<td>3.89</td>
<td>5.88</td>
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<tr>
<td>2013</td>
<td>3.51</td>
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<td>4.07</td>
<td>6.17</td>
<td>13.76</td>
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<tr>
<td>2014</td>
<td>3.72</td>
<td>0.01</td>
<td>4.26</td>
<td>6.46</td>
<td>14.44</td>
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<tr>
<td>2015</td>
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<td>0.01</td>
<td>4.44</td>
<td>6.74</td>
<td>15.12</td>
</tr>
<tr>
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<td>0.01</td>
<td>4.63</td>
<td>7.03</td>
<td>15.80</td>
</tr>
<tr>
<td>2017</td>
<td>4.34</td>
<td>0.01</td>
<td>4.82</td>
<td>7.32</td>
<td>15.96</td>
</tr>
<tr>
<td>2018</td>
<td>4.55</td>
<td>0.01</td>
<td>5.00</td>
<td>7.61</td>
<td>17.17</td>
</tr>
<tr>
<td>2019</td>
<td>4.76</td>
<td>0.01</td>
<td>5.19</td>
<td>7.90</td>
<td>17.85</td>
</tr>
<tr>
<td>2020</td>
<td>4.97</td>
<td>0.01</td>
<td>5.38</td>
<td>8.18</td>
<td>18.54</td>
</tr>
</tbody>
</table>

#### 3.3. PIPELINE ROUTES – DIFFERENT OPTIONS

For all the following alternatives we consider the following average distances:

- Camisea - Porto Velho: 1,255 Km
- Porto Velho - Manaus: 901 Km
- Porto Velho - Cáceres: 1,241Km

**a) Alternative 1:** "Camisea - Porto Velho" Pipeline: This alternative allows the supply of natural gas for electricity generation and industrial markets in the states of Acre (Capital City, Rio Branco) and Rondônia (Capital City, Porto Velho). The nominal pipe size diameter is 450 mm (18 inches), with nine 9 compression stations separated by a distance of approximately 125 km. By 2020, the gas flow may reach 5.85 Million m³/day (see figure 1).
c) Alternative 3: “Camisea - Porto Velho - Cáceres” Pipeline: This alternative allows the supply of natural gas for electricity generation and industrial markets in the states of Acre, Rondônia and Mato Grosso. The nominal pipe size diameter is 650 mm (26 inches) in the initial leg (Camisea - Acre - Rondônia) and of 550 mm (22 inches) in the extension from Porto Velho to Cáceres. Seventeen compression stations will be necessary, with 9 located between Camisea and Porto Velho and 8 between Porto Velho and Cáceres, all at intervals of approximately 125 km from each other. By the year 2020, the pipeline will be transporting up to 5.85 Million m³/day to Acre and Rondônia and 9.63 Million m³/day to Mato Grosso (see figure 3) (5).

Figure 3: Gasoduto Camisea - Porto Velho - Cáceres

b) Alternative 2: “Camisea - Porto Velho - Manaus” Pipeline: This alternative allows the supply of natural gas for electricity generation and industrial markets in the states of Acre, Rondônia and Amazonas (Capital City, Manaus). The nominal pipe size diameter is 600 mm (24 inches) in the initial leg (Camisea - Acre - Rondônia) and 450 mm (18 inches) in the extension from Porto Velho to Manaus. Fifteen compression stations will be necessary, with 9 located between Camisea and Porto Velho and 6 between Porto Velho and Manaus, space at about 125 km from each other. By the year 2020, the pipeline must deliver up to 5.85 Million m³/day in the states of Acre and Rondônia, and 6.32 MM m³/day in the state of Amazonas (see figure 2).

Figure 2: Gasoduto Camisea - Porto Velho - Manaus
d) Alternative 4: “Camisea - Porto Velho, Porto Velho - Manaus and Porto Velho - Cáceres” Pipeline: This alternative corresponds to the full project considering all the proposed legs from the other alternatives. It allows the supply of natural gas for electricity generation and industrial markets in the states of the Acre, Rondônia, Amazonas and Mato Grosso. The nominal pipe size diameter is 750 mm (30 inches) in its initial leg (Camisea - Acre - Rondônia), then 450 mm (18 inches) in the extension from Porto Velho to Manaus and 550 mm (22 inches) from Porto Velho to Cáceres. It will require 23 compression stations, with 9 located between Camisea and Porto Velho, 6 between Porto Velho and Manaus and 8 between Porto Velho and Cáceres. They will be separated by approximately 125 km one from each other. By the year 2020, the gas delivers may reach 5.85 Million m³/day in Acre and Rondônia; 6.32 Million m³/day in Amazonas and 9.63 Million m³/day in Mato Grosso (see figure 4) (5).
4. CONCLUSIONS AND FINAL COMMENTS

• The Camisea field has enough gas to provide the local Peruvian markets, estimated at 18 MMm³/day by the year 2020, and also to supply in competitive basis exporting markets.

• We believe that the most suitable markets are located in the North and Midwest of Brazil.

• The arrival of large amounts of Peruvian gas in the North and Midwest of Brazil would allow the creation of new development poles and boost significantly the regional economic growth, with the attraction of new industries and the stabilization of electricity supply. In addition, natural gas would work as an integration bridge between Brazil and Peru.

• The use of natural gas in the Amazon electricity and industrial sectors would allow the substitution of other expensive fuels such as diesel oil and fuel oil. In addition, several investments in hydroelectricity would be postponed or even cancelled altogether, preserving the forest area and propitiating low energy costs in the region, with important gains in terms of environmental impacts.

• The natural gas sold at 3.00 US$/MMbtu can generate electricity at 40.00 US$/MWh, which already represents a cost reduction of about 67% as compared to the current generation cost (approximately 120 US$/MWh) in the Northern areas of Brazil. There would be almost no more need for energy subsidies in the region.

5. REFERENCES

(1) CARRERA G., Utilização do Gás Natural de Camisea (Peru) para a viabilização de Sistemas Eléctricos e de Gás no Norte e Centro Oeste do Brasil, Universidade de São Paulo, 1998.

(2) Regarding the future energy supply and demand, it was used as reference the "Projection of Energy Supply" published by the Group of Work for Studies about Eletronorte's isolated systems [ELETROBRAS, 1997] and the "Projection of Energy Demand" developed by the Technical Committee for Market Studies of ELETRONORTE [ELETRONORTE, 1996]. Econometrics tools were used for projecting into the 2007-2020 period.


(5) In the city of Cáceres, the Peru-Brazil pipeline can be connected to the already existing Bolivia-Brazil pipeline through a parallel leg that is already under construction from Bolivia to the city of Cuiabá. By such pipeline interconnection, it would be possible to flow the Peruvian natural gas to major Brazilian markets in the South and Southeast region.

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