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Brito, Dagobert and Rosellon, Juan

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The Political Economy of Solar Energy

Dagobert L. Brito
Department of Economics and Baker Institute
Rice University

Juan Rosellón
División de Economía
Centro de Investigación y Docencia Económicas (CIDE)

Abstract: At the present time, solar power is not a competitive fuel for supplying electricity to the grid in the United States. However, an economic model developed by the U.S. National Renewable Energy Laboratory (NREL) forecasts that solar power production costs could drop twenty percent every time output doubles. Commercial demand for solar cells in the United States has been increasing at a rate of twenty-five percent a year. Such cost projections, if accurate, imply that solar power could be a competitive source of power to the U.S. grid by 2010. Eventually, technical progress and falling production costs will render solar power an important source of energy in the future. As technology improves, it may be possible to supply a substantial part of the nation with solar power from sites in the Southwest of the United States and Mexico. Scientists believe that the cost of solar power will drop to the neighborhood of two cents a kilowatt-hour or perhaps even one cent per kilowatt-hour. If there is enough foresight to develop the technology, then solar-derived hydrogen could become a competitive feedstock in petrochemicals. However, if there is no leadership from government, this process of change could take fifty years. With proper leadership, it could be realized in less than ten to fifteen years

Introduction

Solar energy is an enigma. Based on the current costs of producing solar panels and the rate at which these costs have been dropping in the past, it would be reasonable to expect solar power to be the a major source of power in the projections of future energy sources. If the current projections based on the National Renewable Energy Lab (NREL) model are correct [1], solar power could soon be a very competitive source of energy while addressing the problem of producing power without generating carbon dioxide. It would not be subject to political risk. It is impossible to embargo the sun. Given these obvious advantages, the development of solar power should be a high priority policy in the United States. Surprisingly, it is not. The budget for solar research is around seventy million dollars a year, and most forecasts of the sources of energy in the future give solar a very minor role.[1]

Economics of Solar

One of the problems in the evaluation of the economics of solar cells is that many analysts base their analysis on dollars per peak watt. In terms of the economics of capital investments, this is not a very useful manner to evaluate the economics of solar energy.

Solar energy has two major cost components: the cost of the solar panel and the cost of the balance of systems per square meter. Denote these two costs by C_p and C_b. The other key parameters are the efficiency of the panel that we will denote as α ; the number of kilowatt hours per square meter per year that are delivered by the sun at the location of the installation, β ; the rate at which the efficiency of the panel degrades, δ, and the economic life of the project, T .

The cost of solar power for a project, c , is the value that solves the equation

$$C_p + C_b = \int_0^T e^{-(r+\delta)t} \alpha\beta c\, dt \qquad (1)$$

or in discrete time, this also can be written as

[1] An exception is the 2004 report by National Academy of Science on the hydrogen economy which recommended the development of solar energy to produce hydrogen [3].

$$C_p + C_b = \sum_{t=1}^{T} \left[\frac{1}{(1+r)(1+\delta)} \right]^t \alpha\beta c \qquad (2)$$

The term, $e^{-\delta t}\alpha\beta$ or the term $\left[\frac{1}{(1+\delta)} \right]^t \alpha\beta$ is the amount of electricity produced at time t and $e^{-rt}c$ or $\left[\frac{1}{(1+r)} \right]^t c$ is the present value of the electricity produced at time t. The cost of solar power is that stream of income whose present value will cover the capital costs. Note that this does not include such elements as profits or the cost to transmission. If we solve (1) we get

$$c = \frac{(C_p + C_b)(r+\delta)}{\alpha\beta\left(1 - e^{-(r+\delta)T}\right)} \qquad (3)$$

If we examine (3) we see that cost per peak watt, $\frac{C_p}{\alpha}$, is not an adequate measure of the cost of solar power. That measure only considers the cost per square meter of the solar panel, C_b and the efficiency, α. It ignores some very important variables such as the amount of solar energy at a particular location, the interest rate, and the cost of the balance of systems.

In the United States, the amount of solar energy ranges from an average of 3 to 7 kilowatt hours per square meter per day. Thus, for the same installation, the cost of electricity can vary by more than a factor of two.

Another important variable is the interest rate. If the project has an infinite life, the cost of solar power would be linear with the interest rate. Let $c(r)$ be the cost as a function of the interest rate. Figure 1 below plots the ratio $\rho(r) = \frac{c(r)}{c(.05)}$ for $\delta = 0$ and $T = 20$. This is a measure of how much an increase in the interest rate increases the cost of solar power for a 20 year project.

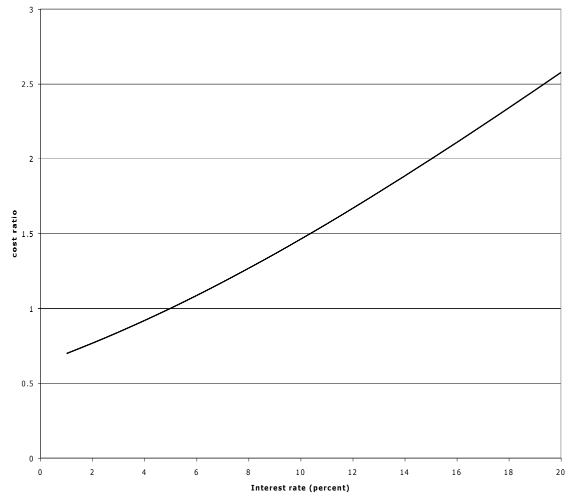

Figure 1 Cost of solar power and interest rate.

In the United States at present (June, 2005), the cost of money to buy houses is in the neighborhood of 5 percent, yet conversations with investment bankers and industry analysts suggest that in the private sector, commercial rates of return in the neighborhood of 12 to 15 percent are necessary for major energy projects to be viable. The National Academy of Science Report on hydrogen as a source of energy uses a discount rate of 14 percent in estimating the costs. Such target rates of return almost double the cost of solar power.

In Figure 2, we plot the cost of solar power using Zweibel's [7-9] cost $85.00 at a production volume of 250,000 square meters per year as a function of the interest rate. We will assume that the solar panels are 9.5 percent efficient,($\alpha = .095$), that the sun delivers 2500 kilowatt hours per year ($\beta = 2500$ }, the panel degrades at a rate of one percent a year ($\delta = .01$), and the project life is 20 years ($T = 20$). The cost of the balance of systems is assumed to be 35 dollars per square meter.[2]

[2] This number is based on Williams (1990) estimate for solar panels tilted at latitude in the dessert. Clearly the cost of balance of systems in such uses rooftops in an urban setting would be higher.

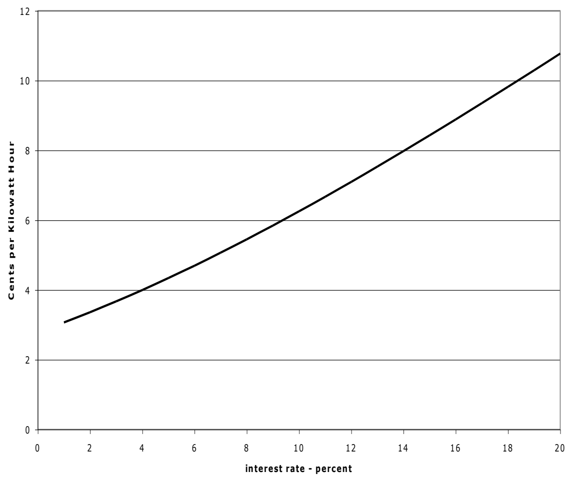

Figure 2 Cost of solar power.

If we examine Figure 2, we see that if the discount rate used is between 5 to 8 percent (as in the housing market), the cost of solar power runs between 4.5 to 5.5 cents per kilowatt-hour to grid. This is competitive with combined cycle gas plants at a price of gas in the neighborhood of $5.00 per thousand cubic feet. However, if a rate of return on the project of 12 to 16 percent is required, the cost of power goes up 7 to 9 cents a kilowatt-hour. At that price, solar power is not competitive with combined cycle generation with natural gas as a feedstock fuel when the price of natural gas is in the neighborhood of $5.00 per thousand cubic feet.

Which is the correct value for the discount rate? Why would the private sector not invest in projects when the rate of return is higher than the cost of capital? At first glance, this seems a paradox. Why would firms pass up projects whose rate of return is greater than their cost of capital? The answer may be that capital is only one of the inputs of a firm. There may be other inputs, some of which are not tradable, which result in firms requiring a higher rate of return than the cost of capital. Thus, solar power may be a viable technology if one just considers the opportunity cost of the resources involved as measured by the interest rate. However, at current technology, solar power is not sufficiently profitable for the private sector to make substantial investment in it.

A related problem is that of economies of scale. The marginal cost of producing solar panels is on the order of $30.00 to- $50.00 a square meter. Studies by Kenneth Zwiebel [7-9] model based on data furnished to the authors by First Solar suggest that costs in the neighborhood of $85.00 per square meter are possible with current technology. However, to achieve such costs, it would be necessary to have a plant volume of production on the order of at 250,000 square meters per year to achieve the necessary economies of scale. This is 25 million peak watts (Mwp). The U. S. market for solar panels last year was 125 Mwp. Thus, at the present time, the volumes necessary to achieve the economies of scale that are needed for solar power to be competitive in supplying power to the net can be sustained only if there is a demand from such large projects as solar fields. But developing demand in that order of magnitude would require a drop in solar cell costs, creating a chicken-egg problem for the technology.

Solving this dilemma will require leadership and entrepreneurship that is not likely to be forthcoming from the private sector.[3] The private sector is driven by a short term profit motive and at the present time, there are more attractive, immediate opportunities than solar power.

Economics and Scientific Research

Over the past fifty years, billions of dollars have been spent on fusion research. If commercially priced, fusion technology could be developed, electrical power would very inexpensive. However, economically viable fusion power requires that at least two technical problems be solved. The first is how to develop a sustained fusion reaction, and the second is how to convert the fusion energy into electricity. Given these technical issues, sustainable fusion energy is still considered to be at least another fifty years away from commercialization.

There is, however, one source of fusion power currently available, the sun. At the distance of the earth from the sun, the sun delivers 1.3 kilowatts per square meter per hour. This is 11,400 kilowatt hours per square meter per year. Locations in the southwest of the United States receive 2,500 to 2,700 kilowatt hours per year. Some of the loss is due to the atmosphere, only one kilowatt per hour reaches the earth's surface. The rest is due to the rotation of the earth. Thus, a spaced based solar plant has a factor of 4.5 advantages over a ground based solar plant. However, a space based solar plant can cost no more that 4.5 times the cost of a solar plant on earth if it is to be competitive as

[3] There are exceptions. Tucson Electric Power Company is currently producing electricity for the grid.

a source of power. It is very expensive to lift mass to orbit or the moon.

One way to get around the cost of lifting solar cells is to build them on the moon. Such a project has been proposed.[4] However, even if a process can be designed so that solar cells can be constructed at a price that can compete with an earth-based system, there is still the problem of transmitting the power to earth. The question that must then be answered is whether transmitting power from the moon to the earth is a less expensive problem than transmitting power from point to point on earth as the earth turns. It seems plausible that any technology that can transmit power from the moon to the earth can also be used to transmit power from point to point on earth. Further, on earth, there is the possibility of developing land-based nano-wire transmission lines as well as electricity storage based on new materials and nano-technology.

Another strong advantage of an earth-based system is that it will be easier to incorporate technical change. The NREL model of costs projects a 20 percent reduction in the cost of solar cells for doubling of output of solar cells. Demand is growing at 25 percent a year. If we combine these two observations, we get an equation for the project cost of solar cells

$$c = c_0 \left(\frac{1}{1+\gamma} \right)^{\frac{1}{\hat{t}} t} \tag{4}$$

where $\hat{t}$ is the time it takes output to double and $\gamma = .2$. To see this, note that after $\hat{t}$ years output will have doubled and the cost drops to $c_0 \left(\frac{1}{1+\gamma} \right)$ and after $2\hat{t}$ years output will have doubled and the cost drops to $c_0 \left(\frac{1}{1+\gamma} \right)^2$. If demand is growing at 25 percent a year, then $\hat{t} = 2.77$ years. If we write (4) in continuous time,

$$c = c_0 e^{-\lambda t} \tag{5}$$

where $\lambda = .072$. Cost can be expect to drop by a factor of two every 9.6 years. See Figure 3 below.

[4] See work of Dr. David Criswell, Director, Institute for Space Systems Operations, University of Houston

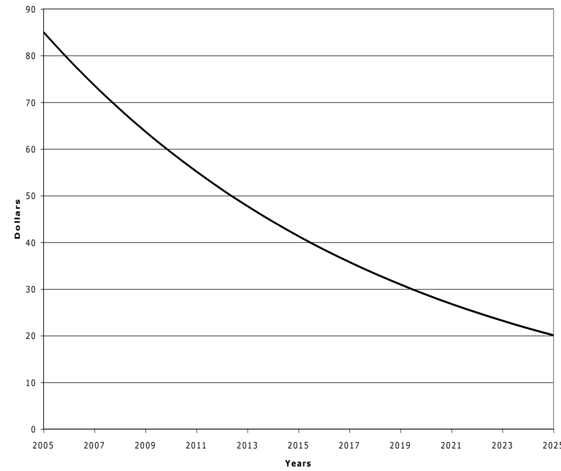

Figure 3 Cost of solar panels.

If these projections are reasonable, they show why moon based solar power may never be an economically viable source of energy. If there is a lead time of ten years in launching a mission to the moon and building the solar plant, then by time the solar plant is built on the moon, technological progress would have made that source uncompetitive compared to the earth solar market. For moon based solar power to be economically viable, it must be able to compete with the technology that will be available on earth when the solar plant is built on the moon. Unless there is reason to believe that the amount of land available will limit the construction of solar fields on earth, moon based solar power is not likely to be economical.

In Figure 4, we plot the cost of solar power as a function of the cost of solar panels as projected by the NREL model. We will assume that the solar panels are 9.0 percent efficient,($\alpha = .09$), that the sun delivers 2500 kilowatt hours per year ($\beta = 2500$), the panel degrades at a rate of one percent a year ($\delta = .01$), the interest rate is 8 percent (r = .08)and the project life is 20 years ($T = 20$). The cost of the balance of systems is assumed to be 35 dollars per square meter.

It should be noted that the NREL cost model is heuristic and does not differentiate between savings due to economies of scale and technical progress. The twenty-five percent increase in demand is also based on historical data and cannot take into account threshold effects where the cost of solar power drops to the point where it becomes competitive in new markets. For example, around a price of four cents per kilowatt hour, large-scale solar fields become very competitive at the current and projected price of electricity. When the cost drops below two cents per kilowatt-hour, solar hydrogen may be an economical alternative to natural gas in petrochemicals [5].

Figure 4 below gives the projected cost of electricity using the NREL model under the assumption that nine percent efficient solar panels at eighty-five dollars per square meter were available. The cost starts at about 5.8 cents per kilowatt-hour and falls to about 2.6 cents per kilowatt-hour over a twenty-year period.

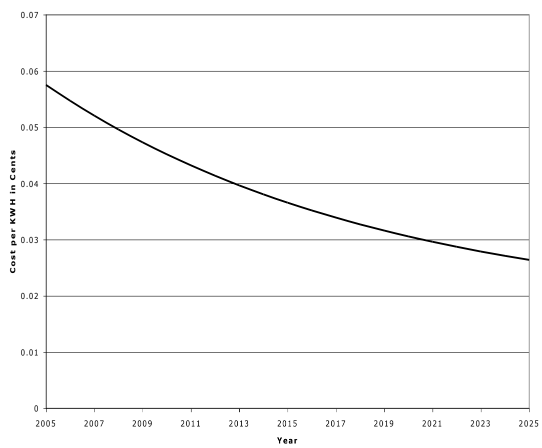

Figure 4 Cost of solar power.

Figure 5 below gives the projected cost of electricity using the NREL model. These projections assume that at the point in time when the price drops to 4.5 cents per kilowatt-hour, demand increases because at that price for solar electricity, large scale solar fields become competitive. The price drops from 4.5 to 3.3 cent per kilowatt in a three year period and then declines to 1.9 cents per kilowatt-hour in the balance of the twenty year period.

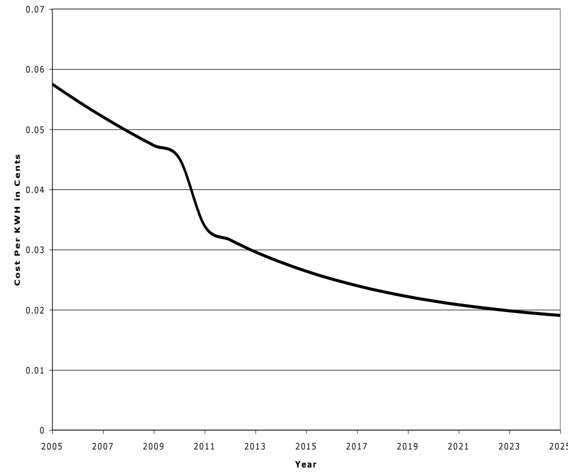

Figure 5 Cost of solar power.

These projections are based on current technology and therefore can be considered conservative. Electric power --in range of 2.5 to 1.9 cents per kilowatt hour-- that does not produce carbon dioxide would be invaluable in solving the energy crisis and the problem of global warming [4]. Thus, it is reasonable to ask the question why solar power plays such a small role in future energy projections and why funding of solar research is so small? At present, the Federal budget for solar research is around 70 million dollars.

There are perhaps several reasons for this lack of understanding of the potential of solar power. First, the advocates of solar power have not done a good job in educating policy makers. They think in terms of cost per peak-watt rather than the cost per kilowatt-hour. There is not a well-developed model of solar power in the academic literature, and this has meant that a clear case explaining the potential of solar power still needs to be made to key policy makers. Political leaders have been thinking in terms of "a million roofs" rather than hundreds of square kilometers of solar panel farms in the desert, producing power for the grid and in the not too distance future, producing electricity at a cost where hydrogen produced from that solar electricity is competitive with natural gas.

Second, and related, there is not a clear understanding of the vast potential availability of solar power in the United States and Mexico. Currently, most of the investment in solar power is taking place in Europe and Japan where the sun delivers 900 to 1,200 kilowatt hours per year. By comparison, the U.S. Southwest and Northern Mexico contains vast uninhabited areas where the sun delivers 2,500 to 2,700 kilowatt hours per year.

To illustrate, United States power consumption is 3.7 X 10^{12} KWH per year. How much land would solar energy require? Let us assume 2,500 KWH per square meter per year, a 60 percent packing factor, and 10 percent efficient solar panels. Under those assumptions, a square meter of land would produce 150 KWH per year and a square kilometer would produce 1.5 X 10^8 KWH per year. So it would take 2.47 X 10^4 square kilometers or 6.1 X 10^6 acres to supply the entire United States electricity consumption. In 2003, the United States used 8 X 10^6 acres to produce 2.81 X 10^9 gallons of ethanol [6]. Thus, the amount of land that would be required to meet all U.S. electric power consumption of the United States (using ten percent efficient solar cells) would be 30 % less than the land currently devoted to the production of ethanol.

A gallon of ethanol can produce 7.5 X 10^4 BTU. The amount of energy produced by ethanol in the United States is 2.11 X 10^{14} BTU or 6.18 X 10^{10} KWH. However, it takes 100 BTU to produce 1.24 BTU of ethanol, so the net energy production from ethanol is 1.19 X 10^{10} KWH. This is about three tenth of one percent of the 3.7 X 10^{12} KWH that could produced on 6.1 X 10^6 acres with ten percent efficient cells. Further, the land used to produce corn to produce ethanol is valuable agricultural land while solar electricity could be produced in the non-arable Arizona or New Mexico desert.

The point of this example is not to argue that ethanol and solar electricity are substitutes, converting one form to the other would involve substantial losses. However, there is more land devoted to producing ethanol that it would take to supply the current electrical consumption of the United States, and it only produces about three tenths of one percent of that amount of energy.

The amount of land is illustrated in Figure 7 below. If we examine Figure 7, we see that more than one third of the United States receives 2,100 kilowatt hours per year and about ten percent receive more that 2,500 kilowatt hours per year. There are also the deserts in Northern Mexico where acreage delivers as much as 2,700 kilowatt hours per year. Thus, it is clear that a shortage of land is not a justification for rejecting the expansion of solar energy.

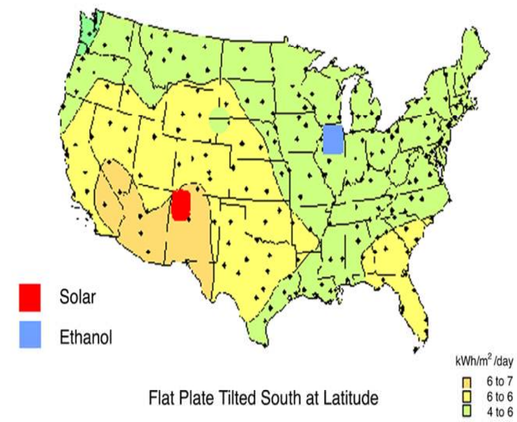

Figure 6 NREL solar map.

An economic comparison of ethanol and solar power is also interesting. The current Federal budget for solar research is $70 million a year. The Federal subsidy on ethanol production is $0.54 a gallon or $1.5 billion a year. The Federal subsidy to ethanol is more than twenty times the current Federal budget for solar research.

The net energy produced by ethanol is 9.83 X 10^9 KWH so if we compute to create the value of subsidy per kilowatt-hour equivalent, we see that the ethanol subsidy is about twelve cents per kilowatt-hour. If solar electricity were given similar treatment, solar power as a business would be booming.

This brings up the third and key reason why solar energy has been neglected. There are no strong vested interests lobbying for solar as such as the farm lobby has lobbied to ethanol and coal states for clean coal research.

Tucson Electric Power and First Solar have an Arizona-based pilot installation that is the second largest installation of photovoltaic modules in the world. As the industry gains experience, one can expect that, predictions by "experts" to the contrary, solar energy will become an important source of energy to the grid as the cost drops below four cents a KWH. At this cost, it would be profitable to ship power from Arizona, New Mexico, and Texas to peak loads in California and Texas. Further, at that point, the drop in cost that will come from the increased volume in the demand for photovoltaic modules will stimulate a further dramatic drop in costs [2]. This will likely happen even if there is not change in policy.

Conclusions

At the present time, at the current levels of production and technology, solar cells are not a competitive fuel for supplying electricity to the grid. At the current level of technology, if the level of production is increased to take advantage of economies of scale, solar cells could become competitive at rates of return in the neighborhood of five to eight percent. But, these rates of return are not attractive enough to attract substantial private investment.

The NREL model predicts that costs drop twenty percent every time output doubles. Demand for solar cells has been increasing at a rate of twenty-five percent a year. If the model is accurate and the trend continues, then solar power will be a competitive source of power to the grid after 2010. At that point, costs will drop dramatically due to economies of scale that result from the increased demand. Lack of understanding of the economics of solar power has thwarted policy interest in this very viable and attractive option.

Solar power at a cost of four cents per kilowatt-hour means that plants in Arizona, New Mexico, and Texas could supply power to the grid for consumption in Texas and California. Moreover, if there is progress in the development of transmission and storage technologies, it may be possible to supply a substantial part of the nation with solar power from sites in the U.S. Southwest and Mexico

We forecast that in 20 or 30 years the cost of solar power will drop to the neighborhood of two cents a kilowatt-hour or perhaps even one cent per kilowatt-hour. This forecast is based on the assumption that there will be no strong policy initiative to accelerate the development of solar power. If there is enough foresight to develop the technology then the drop in the cost of solar power would occur much earlier. Then not only would solar power be available to the grid, but, solar hydrogen could become competitive as a fuel and as feedstock in petrochemicals. This would have a dramatic impact on the U.S. economy and provide a tremendous boost to U.S. national security. Removing the world's dependence on Middle East oil has huge implications for the stability of the international order.

What is needed at this time is strong leadership from an institution such as the National Academy of Science to push for the increased funding for the study of solar power. Economists, engineers and scientists should conduct an investigation to see what technologies - such as nano-technology for storage and transmission - need to be developed. It may be that the problem of the dependence of Middle East oil and the problem of global warming can be solved at a cost below the current subsidies to ethanol.

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Dagobert L. Brito

Dagobert L. Brito is a Professor at the Department of Economics of the Rice University in Houston Texas and External Professor at the Department of Economics of the *Centro de Investigación y Docencia Económicas* (CIDE) in Mexico City. Additionally, he is member of the Academia Mexicana de Ciencias (2006) and member of The International Institute for Strategic Studies in London (1984). He obtained a Ph. D. degree in economics from Rice University .(1970). Dagobert L. Brito has numerous publications on general economic theory, public finance, arms

control/political science, Middle East and energy economics.

Address: C6100 Main, Houston, TX 77005.

Email:brito@rice.edu

Personal Web page:

http://www.ruf.rice.edu/~econ/faculty/Brito.htm

Juan Rosellón

Juan Rosellón is tenured professor the Department of Economics of the *Centro de Investigación y Docencia Económicas* (CIDE) in Mexico City. His main research interests are on economic regulatory issues in the energy sector. He was Repsol-YPF-Harvard Fellow (2003-2005), and Fulbright Senior Fellow (2002-2003) at Harvard University. He was Secretary of the Mexican chapter of IAEE (1999-2001), and member of its advisory board since October 2001. Chief Economist of the Mexican Energy Regulatory Commission (1995-1997). Faculty member of the Program on Privatization, Regulatory Reform and Corporate Governance of Harvard University (1997-2000), and Princeton University (2001). Member of the Mexican National System of Researchers (SNI level II). Ph.D in Economics from Rice University. He has numerous publications on regulatory economics and energy economics.

Address: Carretera México-Toluca 3655, México D.F. 01210.

Email: juan.rosellon@cide.edu

Personal Web page:
http://www.cide.edu/investigador/profile.php?IdInvestigador=53

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