Hydrogen Production

- based on Russian hydropower

August 29, 2006

Items of special interest:

- Investments in large-scale hydrogen production based on Siberian hydroelectricity are not profitable at current price levels, given our estimated parameters.
- Global hydrogen demand is expected to increase which may hike prices and put possible projects into profitable territory.
- High operational gearing - a sector of future interest to follow.

Inside this issue:

- **This letter presents a study of hydrogen production and export from central Siberia to Western Europe.**
- **The intention is to see whether large hydropower resources found in central Siberia can be used for hydrogen production.**
- **Western Europe is facing relatively high energy prices and an increased focus on environmental issues. It is assumed that the demand for hydrogen in this area will increase.**

Introduction

The widespread use of hydrogen as an energy carrier could help address concerns about energy security, global climate change, and air quality. However, hydrogen is not an energy source itself, but must be produced from other energy sources. Large-scale production is usually performed by either reforming natural gas or by water electrolysis and the cost is therefore strongly dependent on the cost of these energy resources.

Reforming natural gas can be done on a large scale with an energy efficiency of about 75 percent, or equivalent to 3.5 kilogram of natural gas per kilogram of hydrogen. Water electrolysis has a typical efficiency of approximately 50 kWh per kilogram of hydrogen. Other alternatives such as the use of biomass or waste are also available, but on a non-commercial basis.

Most of the parameters used in this analysis are uncertain. As today, hydrogen is not a commonly traded commodity, hence important parameters

Use of hydrogen in the transport sector is still under development, and most of the operations today are small scale only: the hydrogen is produced on site.

The most significant element of uncertainty is the transport cost. Most of the existing hydrogen infrastructure is intended for small scale distribution and the costs seen in these projects are not comparable with the scope of this analysis.

Hydrogen chain

This study is based on a production chain in which hydrogen is produced in central Siberia and exported for sale in the respective markets. Power to the electrolyzers is bought from a power producer on a long-term contract at a given price. The current prices at the power exchange, ATS, is roughly 500 rubles per MWh, however our five-year forward estimates for Russia in general are 850 rubles. In this letter we assume that excess hydropower is priced at 270 rubles. A plant of 265 MW is able to produce 116 000 kilogram hydrogen per day which is transported by rail to the customers.

Hydrogen:

Lower heating value (LHV)	33.33 kWh/kilogram
Higher heating value (HHV)	39.41 kWh/kilogram
Density	0.0899 kilogram/Nm^3
Vaporization temperature	20.39 K (-253°C)

Currency rate:

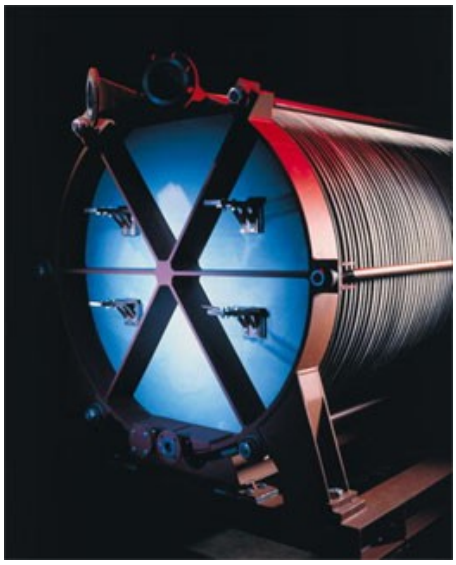
$1 = 26.80 rubles

The production chain mainly consists of the following three elements:

- Electrolyzer
- Liquefier
- Transport

The main characteristics of each element are presented below. According to Norsk Hydro Electrolysers AS, there is limited economy of scale beyond the plant size used in this analysis.

Electrolyzer



The electrolyzer used in this study is manufactured by Norsk Hydro Electrolysers AS and consists of four groups of 24 electrolyzers in a star configuration. This structure gives the best performance regarding minimization of hydrogen production cost.

Electrolyzer Key Figures

Plant size:	265 MW
Availability:	300 days/year
Production rate:	1.3 million Nm^3/day
Plant cost:	$200 million
Auxiliary cost:	$5.5 million/year

Liquefier

The liquefier cools the hydrogen to a temperature of -253 °C. This operation requires a substantial amount of energy, but the investment costs are relatively low.

Key figures liquefier

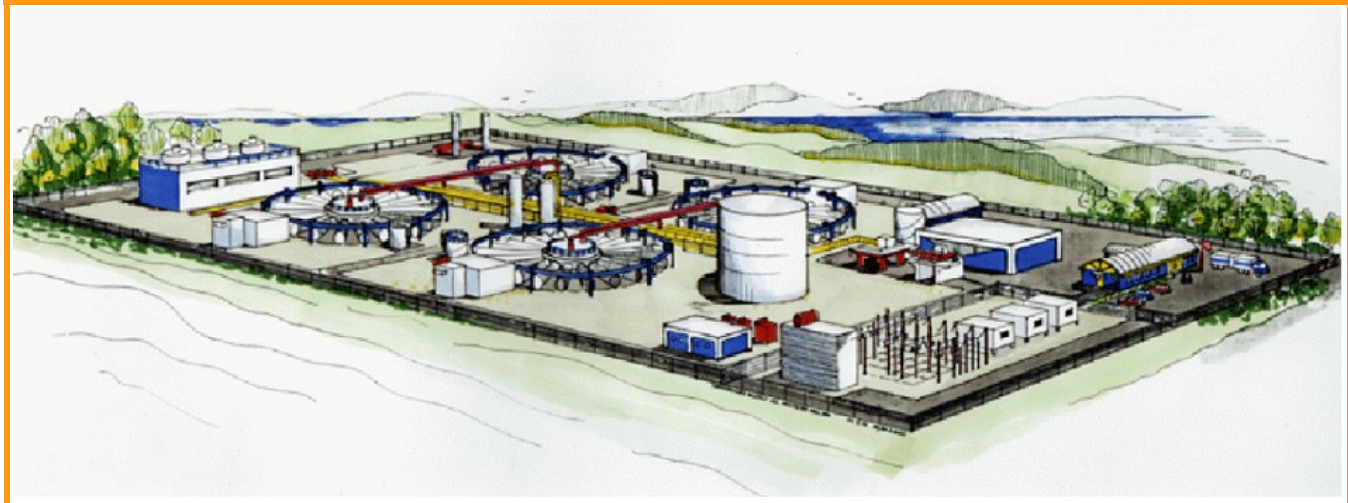
Capacity:	116 000 kilogram/day
Energy use rate:	40 MJ/kilogram
Plant cost:	$15.5 million
Auxiliary cost:	$4.3 million/year

Transport

It is assumed that the hydrogen is transported on large cryogenic railway carriers from the production site in central Siberia to the customers in Western Europe. The cost estimate is based on LNG railway transport parameters with an add-on for hydrogen characteristics.

Key figures transport Western Europe

Boil-off ratio	1.5 percent/day
Transport time:	5 days
Other losses:	3 percent
Transport cost:	$0.6/kilogram



Sketch of a 265 MW electolyser plant, Norsk Hydro Electrolysers

Results

The profit is highly dependent on electricity and hydrogen prices, and the results are presented in two cases with an electricity price of $10 and $25 per MWh respectively. The break-even hydrogen prices are calculated in both cases and the internal rate of return is calculated for different hydrogen prices.

Case I

Electricity price central Siberia:	$10/MWh
Interest rate:	8 percent
Plant lifetime:	25 years
Break even hydrogen price:	$2.25/kilogram
IRR given $2/kilogram:	3 percent
IRR given $3/kilogram:	20.1 percent
IRR given $5/kilogram:	49.4 percent

Case II

Electricity price central Siberia:	$25/MWh
Interest rate:	8 percent
Plant lifetime:	25 years
Break even hydrogen price:	$3.35 /kilogram
IRR given $3/kilogram:	0.6 percent
IRR given $4/kilogram:	18.6 percent
IRR given $5/kilogram:	33.4 percent

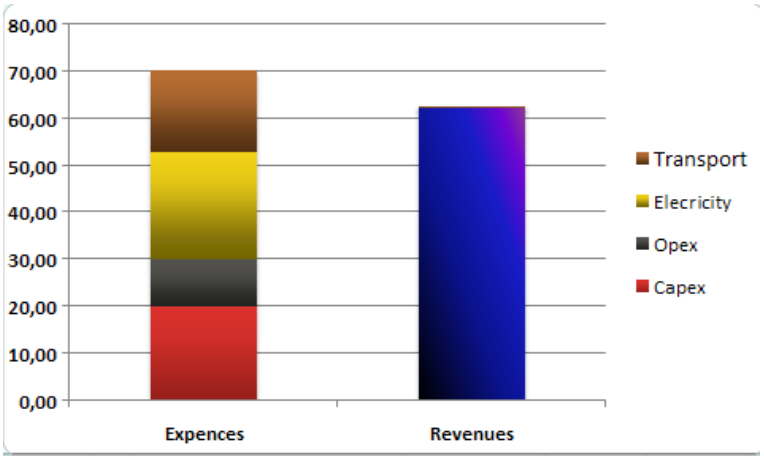
Main results

The analysis indicates that it is not profitable to invest in a 265 MW hydrogen production chain, given a price level of $2/kilogram of hydrogen.

The most significant uncertainty is the expected market price for large-scale hydrogen. At present there is no such commodity market, and hydrogen prices are not public. However, the given information indicates a maximum price of $1.5 to 2/kilogram. (Hydro, Linde, AGA, Invanor).

There is also uncertainty connected with the transport parameters. In this case, a cost of $0.6/kg is estimated based on railway transport with special cryogenic containers, (Kuehne and Nagehl)

Yearly income and expenses, Case I - $2/kg



ROSNOR ENERGO

Capital Business Centre
3rd floor, suite 311
Ilyinka Street 4
103012 Moscow
Russia

C. J. Hambros plass 2c
2nd floor
NO-0164 Oslo
Norway

Analyst: A. Mæland

Telephone/Fax: +7 495 7817929

www.Rosnor.com
Mail@Rosnor.com

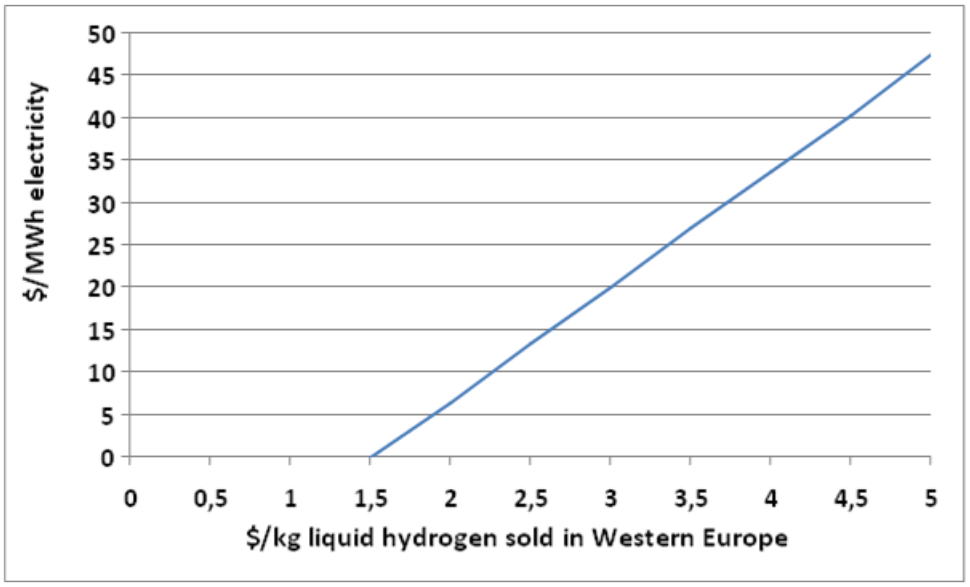
Company profile

Rosnor Energo is a Russian-Nordic advisory services company operating within the energy sector. Our main focus is engagement in Russia's energy markets and the ongoing energy reform in the country. The company's partners have more than 20 years' experience in the Russian energy sector and deregulated markets in Europe and the United States. We are, therefore, well-acquainted with regulatory issues, trading of physical contracts and financial instruments, portfolio risk management, derivatives hedging, production, and transmission.

Rosnor Energo was incorporated in July 2003. Since that time, we have undertaken a wide range of contracts connected with implementing a free competitive market in Russia in cooperation with governmental bodies and electric power companies. We are also involved in matters concerning the reconstruction and optimization of energy production plants.

Our aim is to use our valuable experience as a platform for cross-border cooperation promoting investments in the Russian energy sector.

Break-even electricity price



The plot shows the break-even electricity price as a function of the hydrogen price in Europe given an interest rate of 8 percent. A hydrogen sellout price of $3 per kilogram corresponds to a break even electricity price of $20 per MWh.

Summary

Export of hydrogen as presented in this study is currently not profitable. However, with rising hydrogen demand and increased gas– and electricity prices in Europe, the situation might become interesting. Hydrogen price of $2.2 per kilogram in Europe correlates to a break even electricity price of $9.3 per MWh in central Siberia. If the hydrogen price increases to $3 per kilogram, break-even electricity price is more than doubled to $20 per MWh. The main uncertainty factor is related to transport costs and losses, and hydrogen prices in Western Europe.