Transport or transmit?

Should we transport primary energy resources or transmit them as electricity?

Alexandre Oudalov, Muhamad Reza

When we think of the methods by which primary fuel as found in mines and deposits is converted to the electricity that makes our lights work, we often consider the various steps of the extraction and conversion process. The optimization of this process, however, is incomplete if it does not take a further aspect into consideration: transportation.

Should the power stations be built close to the load centers, with the fuel being brought there mechanically (for example, by rail, ship or pipeline), or does it make more sense to generate the electricity close to the primary energy deposits, and use electrical wires for bulk transmission?

Projections by the International Energy Agency indicate that the global demand for electrical energy will double between today and 2030. Coal and natural gas will be the world's fastest growing sources of electrical energy, accounting for around 70 percent of the increase in electric energy generation over the next 30 years 1. Since sources of primary energy resources are usually distant from the main load and population centers, their exploitation usually requires the bulk transmission of electrical energy (>500 MW) or the equivalent transportation of primary energy resources over a long distance (>100 km). Factbox 1 illustrates a variety of energy transport scenarios. These display different levels of efficiency, reliability and environmental safety. These scenarios are characterized on the one hand by the type of primary energy resource used, and on the other hand by the transport system deployed.

The methods adopted for moving primary energy resources to power plants and then moving the electric energy to load centers is determined by a complex decision making process and depends (amongst others) on the amount of energy to be moved, the distance over which it must be moved, capital and operating costs of the transport system and amount of existing infrastructure [1–3]. Additional factors affecting such a decision are linked to externality cost, which is related to the environmental and social consequences of energy transportation. The authors analyzed the position of ABB's "wire" technologies (HVDC and HVAC) when compared to various methods of transporting primary energy and generating electricity closer to the load centers.

Bulk energy transport model

A bulk energy transport (BET) model was constructed to address all relevant combinations of problem scenarios and technologies, embracing common practice techniques for life-cycle cost analysis with monetization of externalities and supporting sensitivity analysis. 2 illustrates main components of the BET model for a comparison of alternative energy transport options (further details can be found in [4]). The bulk energy transport analysis considers two major options: the transmission of electric energy and the transport of primary energy resources. A total cost of each transport option consists of capital, operating and externality costs Factbox 2. Together with the cost of electricity at the point of delivery to the load centre, these indices are used to rank alternative energy transport options.

HVDC technologies provide strategic opportunities to reduce externality cost.

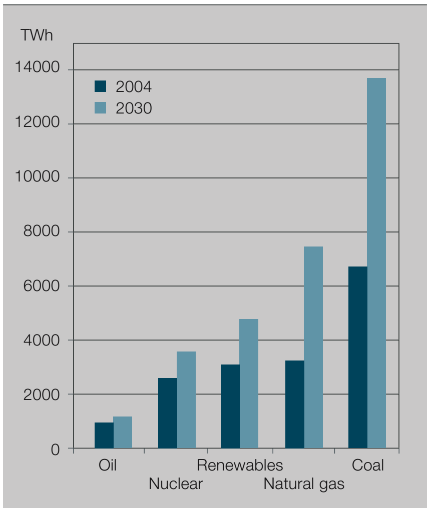
Air-pollution implication

Using an example of air-pollution emissions, the following section illustrates an estimation of externality cost. Air-pollution caused by generation and energy transport includes pollutants emitted by combustion of primary energy resources at the power plant, by rolling-stock engines and pollutants released by the combustion of the additional primary energy resources required to cover transmission losses. The study considered the following air pollutants: CO_2 for global climate change, NO_x, SO_2 for acid rains and aerosols and suspended particulate matters (PM). It also accounts for different air emission-capturing capabilities of power plants and rolling-stock. The total air emission externality cost is a single indicator which aggregates air emission costs of all pollutants for the option being looked into.

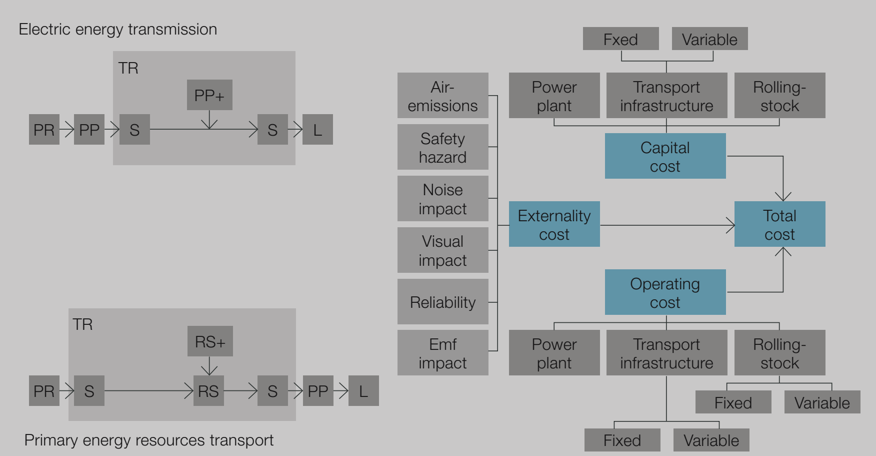
For example, the annual externality cost of CO_2 emission in the case of electricity transmission paired with mine-mouth coal-fired generation is calculated from the following parameters:

- Emission factor in tons of CO_2 per ton of combusted coal

1 World Electricity Generation by Fuel, 2004-2030, Source: IEA, 2006



2 Bulk energy transport model



PR Primary energy resources
PP Power plant
TR Bulk energy transport system
S Station (converter, transformer, loading/unloading resources)
PP+ Power plant to compensate transmission losses
L Electric load
RS Rolling-stock
RS+ Supply system for fuel

Factbox 1 Alternative bulk energy transport scenarios

Primary energy resource	Moving fuel by						
	Wire	Rail	Barge	Vessel	Pipeline	Truck	Conveyor
Coal	HVAC HVDC	Unit trains	Tows	Vessel	Slurry, coal logs, synthetic gas	Impractical for >100 km	Impractical for >50 km
Natural gas		Impractical		LNG vessel	Overland, underground	Impractical	Physically impossible

Transformers and substations

Factbox 2 BET Model components: capital, operating and externality costs

Type	Power plant	Transport infrastructure		Rolling stock	
		Fixed	Variable	Fixed	Variable
Capital cost is linked to production, construction and decommissioning of infrastructure	Power plant capacity. Differs for each energy transport scenario due to the power plant characteristics and the additional power required to compensate transmission losses.	Primary energy resources loading/ unloading facilities or converter and transformer stations at both ends of the route	Transport route: rail track, pipeline, high-voltage overhead line or cable	Circulating rolling-stock: unit trains, tows, vessels	
Operating cost is linked to primary energy resources production and transportation, power generation and transmission, compensation of losses	Fuel and maintenance cost	Electric losses in converter and transformer stations or the lost primary energy resources during loading and unloading of rolling-stock plus maintenance cost	Electric losses in conductors or the lost primary energy recourses during transportation plus maintenance cost	Maintenance cost	Fuel cost
Externality cost is related to the environmental and social consequences of bulk energy transport. If environmental regulations removed all externalities, these costs would be zero. However, it is not efficient for environmental regulation to remove all externalities. Rather, a standard should be set at the level where marginal social benefit of abatement equals marginal social cost. At this level, there will still be externalities that should be considered in decisions about transport. Even assuming that environmental regulations are properly set, the remaining externalities might influence choosing one option for BET over another, eg, an underground cable for transmission rather than overhead lines. In the BET Model, air pollution emissions, safety hazard, audible noise, visual (aesthetic) effect, and EMF impact are considered as major "building blocks" of the externality cost.					

- CO_2 emission reduction efficiency of coal-fired power plant (influences capital and operating costs)
- Consumption rate of coal in tons per year
- Estimated future emission tax per ton of CO_2

In general, air-emission taxes reflect the health and ecosystem impacts of the pollutants being taxed. Today they reach the level of 25–40 $ per ton of CO_2 in some countries [5]. Taking into account the fact that CO_2 emissions have a global effect on the environment, the emission tax does not depend on the geographic location of power plant and energy transport infrastructure within a specified environmental regulation area. However, the other pollutants considered do have a strong local environmental impact. Therefore, power plants and infrastructure for energy transport located close to load centers are subject to much higher emission taxes than those in remote locations.

Case study

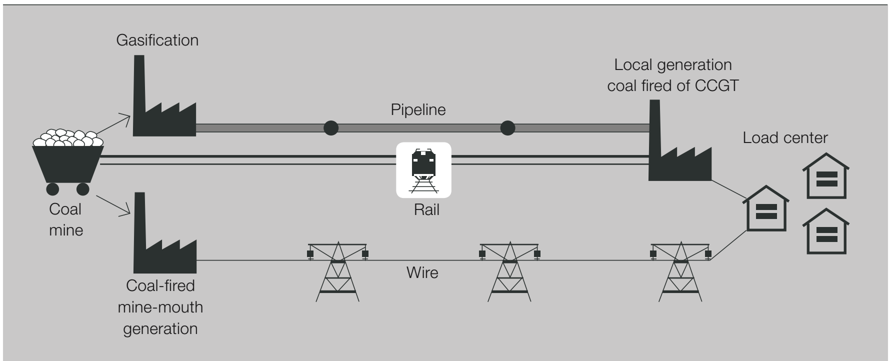
The results of a comparative analysis of a set of bulk energy transport scenarios defined according to state of the art technologies and typical use on the mainland are presented in the following case study. The scenarios considered deal with the transportation of energy from a coal mine (low sulfur, sub-bituminous coal) to the load center by the following means 3:

- Coal by wire (HVAC and HVDC overhead lines and HVDC cable) coupled with a mine-mouth coal-fired power plant
- Coal by rail coupled with a coal-fired power plant in the vicinity of the load center
- Coal to synthetic natural gas (methanation) by pipeline coupled with a gas fired power plant in the vicinity of the load center.

This study is based on the scenario of transporting 1000 MW of electricity (or the shipping of the primary energy resources needed to produce 1000 MW) over a distance of 1000 km. In this first phase of the analysis, it is assumed that:

- Externality cost is not implied in the "business as usual" (BAU) case
- All required data on capital and operating costs are available
- Rail track, power transmission lines and pipeline do not exist and must be built.

3 Bulk energy transport scenarios

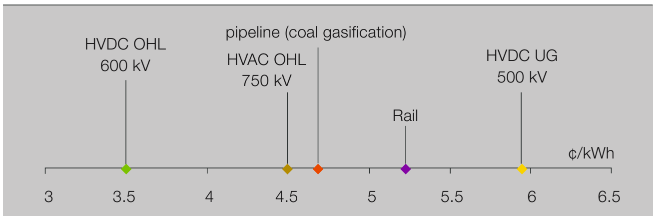


4 illustrates the cost of electricity at the load center including generation and energy transport. The comparison of different bulk energy transport scenarios in the BAU case leads to the following principal conclusions:

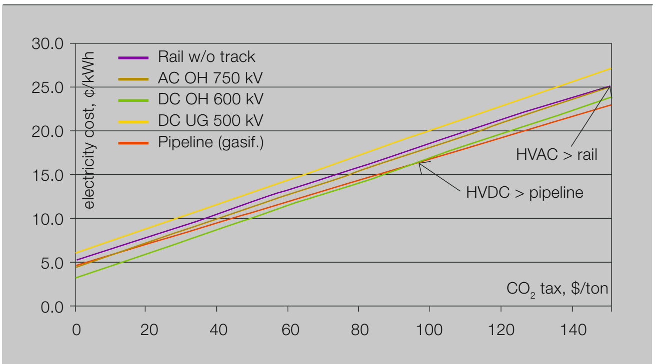
- The ranking of these bulk energy transport systems mainly depends on the capital cost
- Overhead HVDC lines offer the lowest electricity cost,
- The operating cost is the largest component of the coal by rail option

■ Underground HVDC cable is the most costly of the five options.

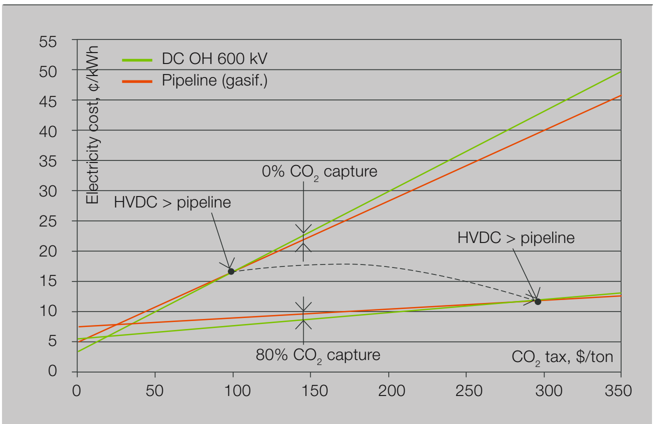
4 Cost of electricity at the load center (BAU case)



5 The impact of CO_2 emission tax on the cost of electricity at the load center



6 The "break-even CO_2 emission tax" for overhead HVDC line and coal to gas by pipeline for 0 and 80 percent of CO_2 capture



The BAU case showed that overhead HVDC transmission option is clearly more advantageous than transporting primary energy resources to the load center and generating electricity locally.

In the next phase of the study, the implication of externality cost (and in particular CO_2 emissions) on the ranking of the different bulk energy transport options were considered. 5 shows the variation of cost of electricity at the load center due to a variation of the CO_2 emission tax in a scenario that sees no CO_2 capture. The left end of the graph shows the zero tax scenario (identical to the BAU discussed above). From here, the electricity cost increases with CO_2 emission tax for all options. Underground HVDC cable has the highest cost because of the higher amount of coal that must be fired to compensate electric transmission losses. An overhead HVDC transmission line is a cheaper option, entailing a CO_2 emission tax of less than \$100 per ton of CO_2, but it can be surpassed by a coal to gas with pipeline option when the "break-even CO_2 emission tax" of \$ 100 per ton of CO_2 is reached. The coal by rail option becomes more economic than overhead HVAC transmission lines for a tax rate of \$150 per ton of CO_2. Present CO_2 emission taxes in Europe are in the range of \$ 25–40 per ton of CO_2.

A very high CO_2 emission tax makes CO_2 sequestration economically attractive. Capturing and nearby storage of 80 percent of CO_2 emissions (this is an economically justifiable limit), the overhead HVDC transmission line would be surpassed by the coal to gas by pipeline option only if the "break-even CO_2 emission tax" climbs to \$ 300 per ton of CO_2 6. Furthermore, the overhead HVAC transmission line will become more expensive than the coal by rail option at a CO_2 emission tax level of \$ 1300 per ton of CO_2. Thus, the capture of CO_2 increases a competitiveness of "wire" technologies (the costs of CO_2 capture and sequestration are taken into account).

According to the BET model, an externality implication on bulk energy transport shows that early conversion of coal to electricity and transmission with HVDC technologies demonstrates a significant improvement over the conventional overland transport of primary energy resources. HVDC technologies provide strategic opportunities to reduce externality cost. The authors believe that it is highly probable that long distance bulk energy transportation will shift from moving primary energy resources to electric energy transmission.

In regard to these predictions it should be noted that the input data used is afflicted with a certain degree of uncertainty.

Alexandre Oudalov
ABB Corporate Research
Baden-Dättwil, Switzerland
alexandre.oudalov@ch.abb.com

Muhamad Reza
ABB Corporate Research
Västerås, Sweden
muhamad.reza@se.abb.com

References

[1] **Bahrman, M., Johnson, B.** (2007) The ABCs of HVDC Transmission Technologies. IEEE Power & Energy Magazine, No. 3/4, 32–44.

[2] **Clerici, A., Longhi, A.** (1998) Competitive Electricity Transmission System as an Alternative to Pipeline Gas Transport for Electricity Delivery. Proc. of 17th World Energy Congress, Houston, TX, USA.

[3] **Bergerson, J., Lave, L.** (2005). Should We Transport Coal, Gas, or Electricity: Cost, Efficiency, and Environmental Implications, Environmental Science & Technology, Vol. 39, No. 16, 5905–5910.

[4] **Oudalov, A., Reza, M.** (2007). Externality Implication on Bulk Energy Transport. Proc. of 27th US Association for Energy Economics Conference, Houston, TX, USA.

[5] European Energy Exchange, EU CO_2 Allowances for 2007–2008, www.eex.de (November 2007).