MECH 4340 Term Project

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Efficient Transportation of Energy

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Abstract

For our energy management research project, we reviewed current technologies and methods for transporting energy from the production site to the consumer end. A range of energy types will be examined, with a focus on oil, gas, and electricity.

A major area of focus of the review is on energy efficiency in the transportation process. Specifically, the amount of energy required per unit of energy transported as a general comparison between different methods/ mediums of energy transportation.

For energy transportation in the form of oil fuels, the techniques used to transport and distribute these products from the production site to consumer were evaluated and compared. A specific case example for this is be bio-gas transportation, and the processes involved in its storage and transport.

Similar to oil, after natural gas has been extracted and processed, it must be shipped physically to consumers. The methods used to compress and pressurize gas, and the various transport containers used were discussed. As well, research on natural gas pipelines and how they

compare against shipping container methods, over both short and long distances.

Technologies for transporting electricity are also researched, mainly long distance methods and the electrical losses during power transmission. This will be a general review of electricity transportation, including nuclear, coal fired plants, hydro or other resources. Only the part of the process after the electricity is produced is discussed.

Introduction

Energy use in the global community is always rising. Large population centers use significant amounts of energy, and while power generation facilities can be built close to population centers, sources of primary energy are often located vast distances from these population centers and must be transported to them for use. Additionally, energy must travel from producers, be they power plants, oil wells or natural gas fields to the individual consumers. Transport of energy is one of the largest sources of energy losses in the energy market. Even if it was possible to extract all of the energy from a primary, or secondary energy source, this energy would still have to be transported to market. Energy can be transported in many ways, and these technologies must be understood in order to reduce losses that occur during the transport of energy in the form of oil, natural gas and electricity.

Natural Gas

Efficiency in transporting Natural gas

Natural gas is a high quality source of energy in high demand for two reasons. Natural gas is an efficient fuel, and it is relatively clean when compared to fuel oil or coal. Currently the USA produces 45 million cubic feet of natural gas a day[1]. Natural gas has a very low density making it very difficult to transport economically and efficiency. The conventional practice for the oil and gas industry for many years was to flare natural gas as it was extracted along with crude oil. This practice was incredibly wasteful in both economic and energy terms and has been discontinued in many countries. This practice was carried out because often it was not worth the effort of transporting natural gas. Natural gas cost up to 10 times as much to transport when compared with crude oil[2]. However, several ways to transport natural gas exist. The two most significant methods are transportation by pipeline, in the form of both compressed natural gas (CNG) and liquid natural gas (LNG), as well as transportation by ship in the form of liquefied natural gas. Other forms of transportation include natural gas hydrates (NGH), moving it in tanks as compressed natural gas, or

1 US Energy Information Administration. Drilling Productivity Report

[2] Review of ways to transport natural gas energy from countries which do not need the gas for domestic use, 1464

transporting the energy in the natural gas as electricity after being converted at a generating station.

Pipeline Transportation of Natural Gas

The majority of natural gas in the United States, Canada, and the world is transported through pipelines. Although other ways for transporting natural gas are widely used, nearly all natural gas which is extracted will eventually be transported through a pipeline, either directly from the natural gas field to a distribution network, or from a port facility where natural gas is offloaded from tanker ships and piped to market. Natural gas pipelines form a network across the area which they serve. Large pipelines called transport lines[3] transport compressed natural gas at high velocities of up to 20 m/sec [4] across large distances. The transport lines operate at high pressures, of up to 10 MPa for overland pipelines and 15MPa for under sea pipelines[5]. This means that large compressor stations are required in order to maintain efficient and economic energy use from the pipeline. Transport lines are fed by gathering lines which take natural

3 Natural Gas Pipelines, p1

4 Natural Gas Engineering and Safety Challenges, p20

5 Natural Gas Engineering and Safety Challenges, p18 gas from the source, and are designed to take advantage of any pressure available from the natural gas wells[6]. The transport lines are then fed into distribution lines which bring natural gas to individual consumers.

Transportation of Liquefied Natural Gas

The easiest form to move natural gas across seas and long distances is in the form of liquid natural gas. Liquid natural gas is transported at atmospheric pressure and approximately 112 Kelvin[7]. The two most energy intensive processes related to the transport of liquefied natural gas is the liquefaction process, and the transportation process[8]. The liquefaction process consists of compressing the natural gas to about 7MPa, and then cooling it using a refrigeration cycle[9]. LNG is transported by ships to the point of use, where it is either fed into a pipeline, or re-gasified for use. The regasification process produces about 600m3 of natural gas at atmospheric conditions for every 1m3 of LNG[10]. Regasification takes place by pumping the liquefied gas through heat

6 Natural Gas Pipelines, 1

7 Feasibility of transporting LNG from South Pars gas field to Potential Markets, 1812

8 Feasibility of transporting LNG from South Pars gas field to Potential Markets, 1813

9 Feasibility of transporting LNG from South Pars gas field to Potential Markets, 1816

10 Reviews of way to transport Natural Gas energy from countries which do not need the gas for domestic use, 1465 exchangers where the gas is heated by either burning fuel, or pumping seawater through the heat exchangers[11].

LNG is transported to market by truck, pipeline, but mainly tanker. Tankers are more efficient for transporting LNG over large distances than pipelines. There are 360 LNG tankers transporting LNG from 25 major export sites[12]. These are capable of transporting a cargo of approximately 125000m3 up to 210000m3 of liquefied natural gas[13]. The fuel, and energy cost for transportation of tanker ships is respectively 2.8 X 10-3 kg fuel/tonne cargo/mile and 87 J/ kg cargo / meter[14]. LNG has an energy content of about 23430 MJ/ m3 or about 55000 kJ/Kg at room temperature[15]. This means that the transport efficiency of LNG is about 630KJ of LNG/J of fuel/ meter travelled. These tankers use LNG as fuel[16], so this number represents a direct energy efficiency. LNG is stored in insulated tanks on board these ships. There are 3 types of tanks in use for transporting LNG. These are the spherical design, membrane design, and

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11 "Introduction to LNG." An overview on liquefied natural gas (LNG), its properties, organization of the LNG industry and safety considerations, 20

12 "Introduction to LNG." An overview on liquefied natural gas (LNG), its properties, organization of the LNG industry and safety considerations, 3

13 Maritime and Pipeline Transportation of Oil and Gas, 34

14 Energy saving potential for natural gas hydrate transportation, 190

15 Natural Gas Engineering and Safety Challenges, 47

16 "Introduction to LNG." An overview on liquefied natural gas (LNG), its properties, organization of the LNG industry and safety considerations, 19 prismatic design. The spherical and membrane designs are the most commonly used[17] with the membrane design currently having the largest share of the market[18]. Because the liquefied natural gas is not cooled during transportation, part of the cargo boils off, and is lost to the atmosphere, at a rate of about 0.23 percent of the total cargo per day[19]. This boil off rate makes liquid natural gas difficult to store for long periods. When the LNG reaches its destination, it must be re-gasified. This process uses 1 percent of the energy stored in the liquefied natural gas[20]. These losses as well as the high energy cost of producing mean that liquefied natural gas for transport is only energy efficient in large scale operations. Typically, a natural gas field will need to produce at least 3 trillion scf (standard cubic feet) of liquefied natural gas over the project lifetime[21].

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17 Feasibility of transporting LNG from South Pars gas field to potential markets, 1813

18 "Introduction to LNG." An overview on liquefied natural gas (LNG), its properties, organization of the LNG industry and safety considerations, 18

[19] *Maritime and Pipeline Transportation of Oil and Gas*, 35

[20] *Maritime and Pipeline Transportation of Oil and Gas*, 35

[21] *Reviews of way to transport Natural Gas energy from countries which do not need the gas for domestic use*,1465

Transportation of Compressed Natural Gas

Compressed natural gas is another form in which natural gas can be transported. It is stored at very high pressures which depend on the chemical makeup of the gas. Rich gasses are composed of hydrocarbons with long carbon chains, and are stored at pressures of 1800 psig[22]. Lean gasses are comprised of mostly methane and ethane, and are stored at higher pressures around 3000psig to 3600psig[23]. Compressed natural gasses are usually transported by pipeline, however, there are two ways which compressed natural gas can be stored efficiently. One way is in a Coselle, which consist of a large number of small diameter pipes coiled into a large circle. The pipes are stored together in large reels, and they gain strength from each other allowing for the use of thinner walls[24]. The second method of transporting compressed natural gas is in long large diameter pipes which are either chilled or kept at ambient temperature. Chilled compressed natural gas reduces the volume allowing more gas to be stored per volume. Compressed natural gas is not an efficient way to move energy, since LNG has a much higher density, and can be transported

[22] *Reviews of way to transport Natural Gas energy from countries which do not need the gas for domestic use*,1467

[23] *Reviews of way to transport Natural Gas energy from countries which do not need the gas for domestic use*,1467

[24] *Reviews of way to transport Natural Gas energy from countries which do not need the gas for domestic use*,1467

more economically. However, CNG is easier to produce, because it only required a compression process and not a refrigeration process. CNG is used mainly for vehicles, but also is transported across short distances for use in energy processes.

Transportation of Natural Gas Hydrates

Natural gas hydrates are another, although not frequently used, but actually a more energy efficient method for transporting natural gas. One reason for natural gas being transported by LNG instead of NGH is because the infrastructure already exists for liquefied natural gas, whereas infrastructure for NGH is less frequent.

Natural gas hydrates are solid compounds which are formed when water molecules form structures around a natural gas molecule, trapping the natural gas[25]. In the natural gas industry, the primary concern of natural gas hydrates is them forming in pipelines. This can cause damage when they go through a compressing station, or it is possible for them to clog pipelines[26]. The reason natural gas hydrates are thought to be more energy efficient for transport of natural gas than liquefied natural gas is

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[25] *Energy saving potential for natural gas hydrate transportation*, 190

[26] *Economic Evaluation of Natural Gas Hydrate as Alternative for Natural Gas Transportation*, 1709

that they only need to be stored at -15 Celsius, and are stored at atmospheric pressure[27]. While LNG returns 600m3 for every 1m3, NGH only returns 170m3 of gas for every 1m3 of NGH[28]. This is offset however by decreased transportation costs. Because NGH is a solid, it is more easily transported, and it does not have to be cooled to extremely low temperatures. Additional losses occur during the re-gasification phase, where for every unit volume of natural gas used to produce NGH, only 70 to as low as 20 percent is returned[29].

NGH is produced by compressing natural gas, and feeding it into a reactor chamber with low temperature water. The mixture is then cooled using a refrigeration cycle and the hydrates form as the water freezes[30]. At the same rate of natural gas transportation, NGH are 48 percent more cost effective than LNG transport of the same size. Two major problems exist which inhibit large scale adoption of this mode of transport. The first is ice formation. During hydrate formation, if ice forms from the hydrate, the natural gas trapped in the hydrate is lost[31]. The second is that the rate of

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[27] *Economic Evaluation of Natural Gas Hydrate as Alternative for Natural Gas Transportation*, 1711

[28] *Economic Evaluation of Natural Gas Hydrate as Alternative for Natural Gas Transportation*, 1711

[29] *Natural Gas Hydrate Production and Transportation*

[30] *Economic Evaluation of Natural Gas Hydrate as Alternative for Natural Gas Transportation*, 1712

[31] *Natural Gas Hydrate Production and Transportation*

production of natural gas hydrates are significantly slower than the rate at which LNG is produced[32]. Although natural gas hydrates are not widely used for transporting natural gas, the energy breakdown for their transportation is available. Of the energy available in a unit volume of natural gas, 14 percent[33] is required for its transportation to market. Of this 14 percent, 25 percent[34] is needed for pre-treatment of the natural gas including compression, and 17 percent[35] is required for the manufacturing of the hydrates themselves. 7.7 percent of the total volume of the natural gas hydrate is required for the actual transportation process[36] which is mainly by ship.

Natural Gas hydrates can only be transported by ship or rail because they are solid. However an NGH ship can carry a larger cargo than a LNG ship of similar size because the cargo does not need to be stored in specialized tanks. A LNG ship carries a load of approximately 125000m3[37] of LNG where as a NGH ship carries a cargo of approximately 250000m3 [38].

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32 *Natural Gas Hydrate Production and Transportation*

33 *Energy saving potential for natural gas hydrate transportation*, 190

34 *Energy saving potential for natural gas hydrate transportation*, 190

35 *Energy saving potential for natural gas hydrate transportation*, 191

36 *Energy saving potential for natural gas hydrate transportation*, 191

37 *Maritime and Pipeline Transportation of Oil and Gas*, 34

38 *Economic Evaluation of Natural Gas Hydrate as Alternative for Natural Gas Transportation*, 1712

Oil and Gas

Oil Pipeline Transportation

Historically in the U.S., the majority of the oil supplied and exported from the west coast was distributed via tanker ships. During hostilities with Germany, subs would attack and sink U.S. Oil tankers, causing large problems with supply and production. As is the case with many technologies, the need for a solution drove the development of long-distance pipelines as a solution to the oil transportation problem.[39]

Oil pipelines have been at the forefront of commercial oil production and transportation for some time, and are what many people first think of when the topic of oil transportation is brought up. There are actually several ways that raw oil resources are transported, as well as several different types of oil pipelines.

The basic structure of an oil pipeline is a large "trunk" pipeline which the oil is first sent through, which has a large diameter and flow capacity and deliver bulk quantity over long distances to a few spots.[40] From these points, smaller pipelines carry the oil to numerous delivery points for commercial/residential distribution and use. Oil pipelines are remotely

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[39] *How Pipelines Make the Oil Market Work – Their Networks, Operation and Regulation*, 1-2

[40] *How Pipelines Make the Oil Market Work – Their Networks, Operation and Regulation*, 11-12

controlled and monitored through a series of pumps and gauges that span the length of the pipeline, which controllers can adjust to control the flow.[41]

The main factors involved in oil pipeline design and operation are the thermodynamic and fluid properties of the oil and the environment the pipe travels through. Over long distances of travel, there is significant thermal losses from the fluid to the atmosphere around the pipeline. These losses are made worse by the long distances travelled from commercial drilling and fracking operations to distribution centres, and the environments in which the pipelines are located. This can be mitigated somewhat by proper insulation and in some cases burying the pipes in the ground, but these measures are still not enough in some cases.

Burying oil pipelines can be a very effective way to prevent thermal losses over long distances, benefiting from the natural ground heat and added insulation.[42] This becomes an issue though, in northern climates where there is a cyclical freezing/thawing of the ground over the course of a year. The frost heaving and resulting pressures presents a risk to the wall structure if the pipe is not designed to tolerate these forces. However, as

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[41] *How Pipelines Make the Oil Market Work – Their Networks, Operation and Regulation*, 12

[42] *Study on the water-heat coupled phenomena in thawing frozen soil around a buried oil pipeline*, 1477

the heat from the pipeline itself interacts with the surrounding frozen soil and ice, it melts the ice and saturates the immediate soil with water, which has a lower thermal conductivity than the ice, and actually helps to maintain pipe temperature.[43]

The selection of a transportation method for oil products is largely based on economics, with pipelines being favoured when available.[44] In a comparison between a pipeline and a trucking system of transportation, "Assuming each truck holds 200 barrels (8,400 gallons) and can travel 500 miles per day, it would take a fleet of 3000 trucks, with one truck arriving and unloading every 2 minutes, to replace a 150,000-barrel per day, 1,000-mile pipeline."[45]

Evaluation the energy efficiency of pipeline transportation is done on the basis of losses incurred through the transportation from one point to another. The efficiency is defined as the ratio of stored energy at the end of the pipeline to the stored energy at the beginning. The losses between these points are mainly due to work that has to be applied to overcome

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[43] *Study on the water-heat coupled phenomena in thawing frozen soil around a buried oil pipeline*, 1487

[44] *How Pipelines Make the Oil Market Work – Their Networks, Operation and Regulation*, 10-12

[45] *How Pipelines Make the Oil Market Work – Their Networks, Operation and Regulation*, 2

wall effects and the friction within the pipeline, and also has to consider the gradients and terrain that the pipeline travels over.[46]

Oil Truck Transportation

Oil trucking is another method of transportation, where instead of a dedicated, installed pipeline, a series of tanker trucks transport the raw product as pressurized liquid between the extraction point and the processing point, and then on to the consumers. Of the various methods for oil transportation, trucking has the advantage of being the most versatile in terms of where and when you can transport materials.

This is especially apparent when remote, short-term projects are considered. Construction of either pipelines or railroad tracks is a significant time and capital investment, whereas trucks are mobile and can be brought to a site ready to transport material. The selection of trucks as the method for energy transportation for oil products is only economical in situations where the source of oil will be short lived, so that a return on the investment of a pipeline or railway would be inadequate, or where the

[46] *Estimation of the Energy Efficiency of Oil Production and Pipe-line Transportation Systems*, 1216-1218

location is too remote, and the infrastructure for rail or pipeline isn't available.[47]

Oil Railway Transportation

A third way in which oil is transported is via rail cars. Similar to trucking, the oil is pressurized and stored in tanker cars, which form the body of the train, and travel from the extraction site to processing sites, and on to distribution points. Railway transportation can be generally categorized as long or short haul, depending on the distance that the system spans. Short haul railway transport is primarily between substations, moving oil relatively quickly between two processing or distribution points. Long haul transportation would be a long distance railway that transports oil from a remote location to a processing site far away, or from one production facility to a far away distribution centre.[48]

The combination of both railway and trucking transportation is the preferred method for "flexible pipeline" methods of transporting oil. This is a concept name given to the combination of short rail line transportation and trucking, to quickly set up and maintain a distribution line from an

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[47] *Shale Oil and Gas Revitalizing Inland Transportation Networks*, 63-65

[48] *Shale Oil and Gas Revitalizing Inland Transportation Networks*, 62-64

extraction site, without having to develop the more intensive infrastructure of a full pipeline system.[49] As said previously, this is the kind of transportation system that would best serve a remote location that does not have much local infrastructure, or a site which is expected to be short lived, relative to the time and energy costs of pipeline construction.

Rail transportation suffers from the same economic drawbacks as trucking for long term sustained transport though, with relatively low efficiency compared to a developed pipeline system. A comparison of pipeline and train transportation by volume illustrated that, “Replacing the same 150,000-barrel per day pipeline with a unit train of 2000-barrel tank cars would require a 75-car train to arrive and be unloaded every day, again returning to the source empty, along separate tracks, to be refilled.”[50] This traffic volume requirement is the main reason behind the preference of pipeline over railway for transportation. In the overall process of transportation, the extra fuel and labour expended represents energy costs that detract from the energy that is gained by transporting the oil to a site to be consumed.

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[49] *Shale Oil and Gas Revitalizing Inland Transportation Networks*, 64

[50] *How Pipelines Make the Oil Market Work – Their Networks, Operation and Regulation*, 3

Biofuel Transportation

In the article “A comparison of pipeline versus truck transport of bio-oil”, the specific case example of bio gas transportation is examined, comparing the emissions and energy consumption of pipeline and trucking options.

Bio-gas is an organic fuel which is a compressed and processed form of organic material such as trees or corn. The appeal of bio-gas is that the carbon emissions created form burning the fuel are close to equivalent to the carbon that is absorbed and processed by the plant matter before it is harvested for fuel, which makes bio-gas close to a zero-emission fuel when the entire cycle is considered.[51] This means that the bulk of the emissions from the production and consumption are created in the transportation of the fuel, so the transportation processes are a main focus in reducing the energy losses of bio-gas production.

When evaluating emissions for pipeline transmission, the source of the electric energy used to heat the fuel and to run the pumps is the main factor in determining the amount of emissions. Renewable energy sources

[51] *A comparison of pipeline versus truck transport of bio-oil*, 414-415

such as hydro or wind produce considerably less emissions during the electricity production process.[52]

The results of the study showed the following values for the energy consumption and emission values of pipeline powered by hydro-based and coal-based electricity, as well as trucking:[53]

	Pipeline (hydro-based)	Pipeline (coal-based)	Trucking
Energy Consumption (MJ m^{-3} k^{-1})	3.946	3.946	2.59
Emissions (g of CO_2 m^{-3} k^{-1})	17.17	344.89	89

This data illustrates the point that pipeline transportation is preferable in terms of emissions, only if the electricity is supplied through a renewable energy source. Otherwise, the trucking option has less emissions and if preferable. A large deciding factor in this is where the bio-gas production takes place. If it is in close proximity to a hydroelectric dam or wind farm for example, then using renewable power is attainable and the pipeline is preferable.[54]

[52] *A comparison of pipeline versus truck transport of bio-oil*, 416

[53] *A comparison of pipeline versus truck transport of bio-oil*, 419

[54] *A comparison of pipeline versus truck transport of bio-oil*, 19-20

Electricity

Electricity Grid Economics

Electrical energy transmission is one of the most common and widely used transportation systems for energy. In many cases, it is also the final step in the energy transportation process of oil and gas resources, which fuel power plants in order to convert their chemical energy into electricity for consumption. Compared to gas and oil systems, the process of transporting electricity is much more difficult, because of the complex nature of the electrical grids, maintaining a constant supply to meet demand at all points. In oil and gas, the energy (material) can be stored in loops or closed containers, and be available for use when needed, whereas electricity must be constantly flowing in the circuit.[55]

Management and operation of electrical transmission systems is a large factor in the economic feasibility of electricity transportation, since the system requires much more than just the power lines that we see every day. Some of these include control systems and monitoring of energy imbalance and demand, load monitoring and sharing, as well as significant safety measures.[56] A commercial power transportation system is connected

[55] *Lessons from the history of independent system operators in the energy sector*, 42

[56] *Electricity Transmission: An overview of the current debate*, 90

to multiple nodes of distribution at once, and failures in equipment have the potential to overload the system if one part of the circuit is disrupted. It is for this reason that most power lines are built with a 2-3 safety factor, meaning that up to three lines could be damaged or fail, without causing a surge or overload on another line that would cause damage to the equipment or other property.[57]

Electrical energy is priced mainly by one of two methods. Either on a nodal basis, with each node representing a specific zone that is supplied by the system, or by a set rate for the entire system, independent of individual node conditions. Control of these prices, as well as monitoring of the electrical transmission itself is handled by transmission system operators (TSO) and independent system operators (ISO), entities that work in a natural monopoly at the centre of electricity transmission.[58]

The difference between ISOs and TSOs is that ISOs don't hold any stake in the equipment, that is to say they don't own any of the equipment or have any financial stock in it. Their focus is on reliability and accessibility for producers and consumers, and especially to have a reliable and constant supply for large grids in cities. TSOs are part owners of the

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[57] *Lessons from the history of independent system operators in the energy sector*, 45

[58] *Lessons from the history of independent system operators in the energy sector*, 43

equipment and facilities involved in power transmission, such as third party companies outside of the government or regulatory body.

These TSO operators have the responsibility of setting efficient prices for the use of different transmission assets, to ensure a reliable service is available to producers and consumers. A large part of this is monitoring and dealing with congestion in the system which occurs when one area is oversupplied or overdrawn. Nodal pricing provides a good solution to this, with variable prices at each node that can be adjusted to help regulate the congestion.[59] Along with this, "there is the potential for market abuse (i.e. market price manipulation) at particular nodes. These abuses may be individually small in absolute terms of their financial impact but could be collectively large."[60]

In the management of electrical transmission systems, there are disconnects between the TSO and ISO, as well as between individual energy service regions which border each other. The ISO and TSO need a high level of communication and information exchange, to keep both bodies informed of the needs of the system.[61] In the event of a crisis or equipment

[59] *Lessons from the history of independent system operators in the energy sector*, 38-43

[60] *Lessons from the history of independent system operators in the energy sector*, 35

[61] *Lessons from the history of independent system operators in the energy sector*, 45

failure, communication is key between them in order to effectively fix the problem, as well as to supply information and alternative services to producers and consumers in the meantime.

For example, “Different classification of transmission voltages between England and Wales on one side and Scotland on the other created problems for the ISO in defining what assets it had operational control over.”[62] This illustrates the need for standardization and communication between not just ISOs, but all forms of operating bodies involved in electricity transmission. One of the contributing factors to this issue between the ISO and TSO is the difference in what is incentivized. The ISO is interested in maximizing flow to have the most possible available power for sale and transmission, whereas the TSO aims to reduce maintenance and repair costs of their network.[63]

Grid Efficiency and Smart Grids

The major difference between smart grids, and the existing electric power grids is that the existing electric grids only support power flow in a single direction.[64] In the traditional grid, power is fed from power

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[62] *Lessons from the history of independent system operators in the energy sector*, 45

[63] *Lessons from the history of independent system operators in the energy sector*, 43

[64] *Smart Grid Applications and Developments*, 5

generation stations to consumers directly through transmission lines. Traditional power grids have problems relating to peak loading, as well as difficulty integrating with renewable energy sources because most renewable energy sources which generate energy like wind or solar are not always available. Smart grids can get better use out of renewable energy sources by integrating more easily with these sources of energy, and helping to flatten demand curve, as well as generate power and store electrical power more efficiently for use during peak loading of the grid. Smart grids operate by interacting with information services like building energy management systems, and storing power generated in below peak hours and releasing it during peak hours. Whereas traditional grids use power plants to generate power during the peak load, smart grids can generate extra electricity during off hours and store it in by raising hydro reservoirs where a turbine can generate electricity when needed, or in other energy storage devices and processes. Smart grids are made possible by the advanced communications and control systems technologies that they employ, and are one of the more technologically advanced forms of energy transportation.

Conclusion

In conclusion, the importance of developing sophisticated energy transportation technology is made apparent for all three mediums. As more energy is consumed and more sources are needed to supply the system, the locations at which energy is produced and extracted become more remote and removed from the industrial or urban centers where the energy is intended to be used. The deciding factors on which method of transportation is used for a certain type of energy is based on the economic feasibility that is defined by the energy cost of transporting per unit of energy that is actually transported, as well as the accessibility and life cycle of the energy source. These methods need significant infrastructure to support them in order to have a decent level of efficiency, and developing this transportation technology will be a key factor in the future development of new energy sources in remote areas.

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