

A STUDY ON THE FEASIBILITY OF SOLAR POWERED RAILWAY SYSTEM FOR LIGHT WEIGHT URBAN TRANSPORT

Syed Husain Imran Jaffery¹
School of Mechanical and Manufacturing Engineering,
National University of Sciences & Technology,
Islamabad, 44000,
Pakistan.
imran@smme.nust.edu.pk

Mushtaq Khan
School of Mechanical, Aerospace and Civil
Engineering
University of Manchester, M13 9PL, UK
Mkhan_nust@yahoo.com

Hassan A. Khan
Department of Electrical Engineering
Lahore School of Management Sciences
DHA, Lahore, 54792,
Pakistan
hassan.khan@lums.edu.pk

Sarfraz Ali
College of Civil Engineering,
National University of Sciences & Technology,
Islamabad, 44000, Pakistan
sarfrazengr@yahoo.com

ABSTRACT

In order to advance towards conceptual engineering of a solar-powered-high-speed-passenger-rail system in a developing country like Pakistan, it is imperative to understand the basic comparison of this technology to existing rail system. The current rail system in Pakistan is based on fuels which fall in the category non-renewable fossil fuels and are detrimental to the environment. For growing urban population across the globe, trains can help mitigate traffic congestion, reduce reliability on imported fuels and improve air quality and hence overall quality of life.

1. INTRODUCTION:

Fossil fuels have been at the the chief source of energy consumption since the dawn of industrialization [1]. Overall, mineral oil accounted for 36.3 % of all fuel consumption in 2010 (excluding electricity generation) [2]. As the demand for energy rises across the globe to fuel the expanding international economy, fossils fuels are fast getting depleted. It is estimated that the global crude oil supplies have already reached the peak production level [3]. Furthermore, fossils fuels that include mineral oil, natural gas and coal emit CO₂ among other pollutants that cause global warming, ultimately leading to drastic climatic changes, rising sea level and extreme natural disasters in the form of floods, hurricanes and droughts.

Among the chief contributors towards greenhouse emissions is the transport sector. These include automobiles, buses, trains and air transport. The transport sector contributes to roughly (13.4) % of the total contribution towards greenhouse emissions (Figure1). [4]

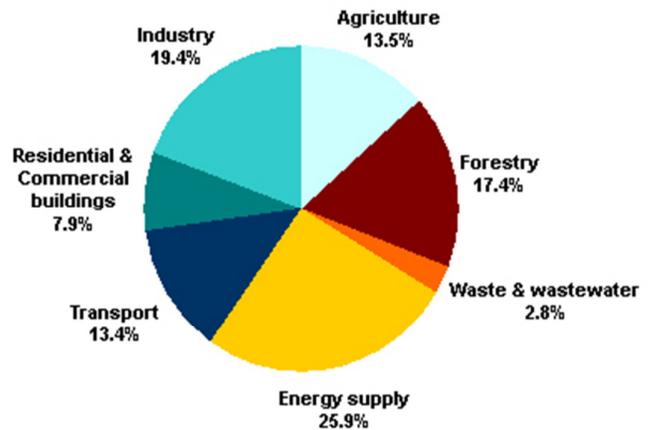
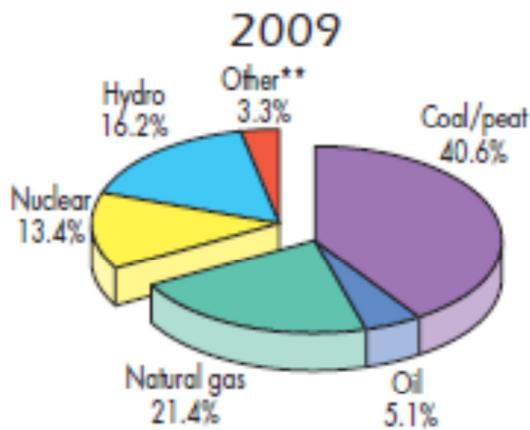


Figure 1. Percentage contribution of various sectors towards greenhouse emissions [4].

Even the usual zero emission modes of transport in used today indirectly get energy from fossil fuels. The electric locomotives in railway transport gets electricity from the natural grid. The production of electricity in 2009 was 20,055TWh out of which only 16.2 % was hydroelectricity and 13.4% nuclear, while fossil fuels accounted for 67.1% of the total electricity generated globally (Figure 2a) [1].

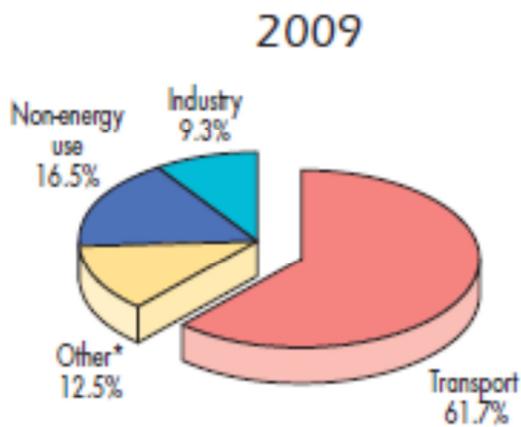
Figure 2b shows the share of world oil consumptions in 2009 wherein the transport sector consumes 67.1% of the total world oil consumption.

¹ Corresponding Author



20 055 TWh

a. Fuel shares of electricity generation
 **Other includes geothermal, solar, wind, biofuels and waste, and heat.



3 462 Mtoe

b. Shares of world oil consumptions in 2009
 *Agriculture, commercial and public services, residential and non-specified other
 Figure 2. [1]

Hydrogen powered cars, a subject of extensive research these days also uses electricity to produce hydrogen by electrolysis, since hydrogen is not found freely in nature. True zero emission sources of energy must therefore be harnessed so that there is less dependence on fossils fuels and therefore less threat to the global environment. These sources include nuclear power, wind energy, tidal energy, wave energy and solar energy, just to name a few. Nuclear energy invokes serious safety issue as has recently been

witnessed in the Japanese earth quake-tsunami triggered mishap of Fukushima nuclear power plant. Apart from this recent nuclear accident the nuclear power industry has experienced several serious accidents including the Chernobyl and Three Mile Island incidents.

Since fossil fuels, wind energy, wave energy, all have a common source of energy in the form of solar energy, it is only natural to look for means to harness this huge potential of clean energy. Overall, the earth receives 162 PW useable solar radiations. Out of this 42 PW are immediately reflected and scattered in the upper atmosphere, leaving a stream of 34 PW radiating back into space. Once the radiation enters the atmosphere, several reflections and absorptions take place [5]. By assuming a single reflection off the Earth's surface and that the same fraction of reflected radiation off the surface is absorbed in the second pass though the atmosphere as the original incoming radiation, 86 PW was reported to fall incident on the Earth surface. Overall, of the 120 PW entering the lower atmosphere, 31 PW were reported to convert to thermal energy in the atmosphere, while 38 PW becomes thermal energy in the land and oceans. 41 PW was reported to cause evaporation of water, and 5 PW radiations reflected off the surface and escapes into space [5]. The enormous power the sun delivers to the earth can be gaged from the fact that the San Francisco earthquake of 1906, with magnitude 7.8 Richter scale released an estimated 10^{17} joules of energy, which is equal to the amount of energy the Sun delivers to the earth in one second. Earth's ultimate recoverable resources of crude oil at 3 trillion barrels, would yield 1.7×10^{22} joules of energy, which the Sun supplies to Earth in 1.5 days. The amount of energy humanity uses annually stands at around 4.6×10^{20} joules, which is about the amount of energy delivered to the earth by the Sun in one hour. The enormous power that the Sun continuously delivers to Earth was reported to be 1.2×10^5 terawatts, which dwarfs every other energy source, renewable or non-renewable [6]. The harnessing of solar energy, however, comes with its own challenges. The high price of solar panels and their maintenance cost are among the main challenges that hinder their extensive usage infeasible. However, with the advancement of technology and the availability of advanced material, photovoltaic devices, that can be used to convert solar radiation to electricity, are becoming more economical and efficient. However, more research needs to be carried out in the right direction so that feasible solutions can be discovered.

2. URBAN TRANSPORT AND PV

Photovoltaic devices convert solar energy into electricity. The electricity produced is in the form of direct current

(DC). To be used as electricity for domestic consumption, this must be converted to alternating current (AC) and fed into the national grid. This conversion leads to energy losses. The typical efficiency associated with such conversion is around 87%.

The Transport sector however does not need such conversion as it can utilize DC current directly. While solar transport has been a subject of extensive research, most of it has been focused on solar powered cars. However, solar cars have their draw backs in that all power produced must be generated onboard. Furthermore this mode of transport is prone to scratch and dents causing greater maintenance costs. As compared with this option, the alternative, a solar power rail transport system could be more viable for a number of reasons. Firstly, since railway transport is restricted to predetermined track ways, that are usually isolated from thorough fares, the possibility of scratch and dents is minimal as compared with road transport that includes cars, buses and trams. Also, since the path is predetermined, it is also possible to generate part of the electricity by utilizing support structure that includes plat forms, track sides, passenger shades. Also, since the journey stops are pre-planned, techniques like regenerative braking can also increase the overall efficiency of trains.

All these positive aspects, besides the fact that such a mode of transport would utilize DC electricity warrants serious research towards making it a viable commercial option. It is already known that railway transport is a more efficient mode of transport as compared with road transport. The typical energy consumptions per passenger for common modes of transport in 2009 are given in Table 1 [7].

Table 1 Energy consumption of common modes of transport

Mode of transport	Energy consumption (BTU/passenger mile)
Cars	3538
Buses	4242
Railway (intercity)	2435
Railway (transit)	2516
Railway (commuter)	2812
Railway (average)	2594
Airplanes	2826

Table 2 gives a comparison of common modes of transport in terms of their CO₂ emissions [8]. It can be seen from the statistics presented therein that the carbon foot print for railway transport is least among the common modes of transport, making the railway system the most environment friendly mode of passenger transport.

Table 2 Average CO₂ emission for common modes of transport

Mode of transport	CO ₂ emissions (g/passenger km)
Cars	110-170
Buses	30-40
Trains	2-5
Airplanes	150-170

3. DETAILED ANALYSIS ON PROPOSED RAILWAY TRANSPORT SYSTEM

Urban rail transport is widely used across the globe transporting millions of passengers to their destinations every day. Such a mode of transport is safe, efficient and comfortable. Examples of such systems include the London tube system, the New York subway system, the Shanghai metro and Tokyo subway. However, for the solar/photovoltaic option to be effectively utilized on a rapid transit system, it must be well exposed to solar insolation. It must therefore be raised well above ground level and must not be shadowed by buildings. Raising its level could be made economically viable by utilizing the support structures for commercial centers. Simply put, the tracks could be elevated on structures housing commercial activities like shops and offices. In turn, these centers would gain easy access by the same transit system they are supporting.

Railway transport is often synonymous with heavy carriages moving along metallic tracks. However, in order to make solar powered railway transport more efficient the carriages must be designed light weight, while at the same time they must be stable at efficient speeds. In this context, the authors are working on stable track designs that would be able to support light weight high speed railway system. For this purpose, a case study is being undertaken on the prospects of launching such a system in a tropical metropolis (Lahore).

Fortunately Pakistan lies in a belt with average solar insolation of about 525 W/m². Taking a practical example of a light weight train, typically a light rail carriage with a design load of carrying 160 passengers is powered by one DC motor per power truck with typical dimensions.

4. FUTURE WORK: A CASE STUDY FOR A TYPICAL TROPICAL CITY

The aforementioned statistics warrant a serious research toward the designing, analysis and prototyping of a PV based light railway system. In this context, the authors are in the process of launching the design and analysis phase of this project. This phase will involve detailed mechanical

designing based on scaled down modelling, analysis and testing and evaluation. Once this phase has been completed, a full scale prototype will be developed and tested. Once this phase is successfully completed, the project can be launched on a commercial scale.

A typical solar power railway station would be designed to receive maximum solar insulation. This depends on two major factors, firstly, orientation of the sun and secondly, the surroundings through which the train would pass. In Lahore, the movement of the sun from rising till setting is trending east-south in morning and west-north in the evening. The surrounding of the likely train route would have buildings of varying shapes and heights. This necessitate that solar railway building should be designed and oriented with slanting roofs and height of solar railway line is adjusted such that it receives maximum possible insulation throughout the day along the entire route. A suggested layout of the solar railway station is shown in Figures 3 through 5. Salient features of a typical solar station are:

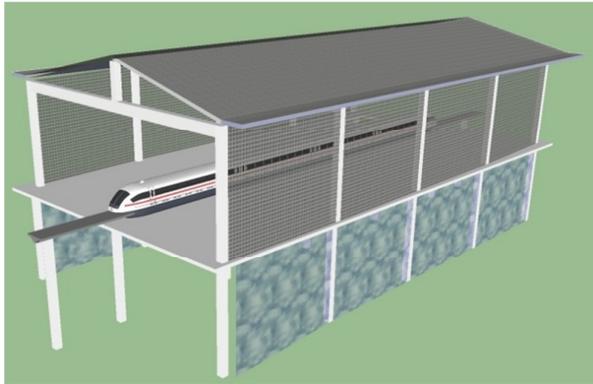


Figure 3. Isometric view of the solar station

- A longitudinal building which has maximum exposure to sun.
- Ground floor can be used for elevators and commercial activities.
- Roof will be used for solar panelling.
- Side walls of first floor will also be used be for solar panelling.
- Sides and roof of the train will be used for solar panelling.



Figure 4. Front elevation of the solar station

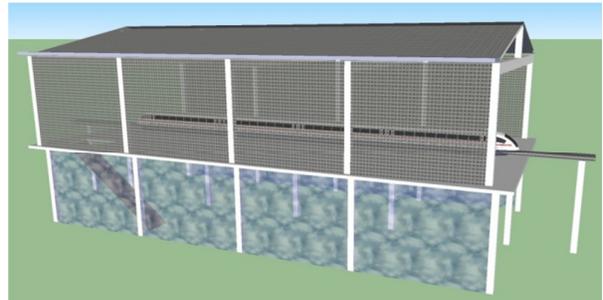


Figure 5. Side elevation of the solar station

5. CONCLUSION

- The age of low cost fossil fuels is over and that warrants serious research into the development of alternate fuels.
- The transport sector consumes 61.7% of the world oil consumption while its contribution towards greenhouse emissions stands at 13.4 %.
- From the economic as well as environmental point of view, research towards the development of alternate energy options for the transport sector is deemed necessary.
- Railway transport can be considered the most energy efficient and environment friendly mode of transport.
- Since the sun is the largest source of energy on earth, this research presents a case to carry out research towards the development and commercialization a light weight solar railway system.

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