WET Nexus between the three sectors – 'Waste to Energy for Transport'

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ABSTRACT

Waste, Energy and Transport are three of the main sectors of the human society. The three sectors have substantially been studied in their individual right and there is a plethora of literature available on them individually and also collectively in varying combinations. For instance, Waste to Energy is a well-established field, and so is the energy usage by the transport sector. However, there is an extreme knowledge gap in connection to energy being generated by incinerating waste in order to propel the means of the transport be it in air/aviation, terrestrial/automobile and locomotives or water/marine vessels. The paper focuses on this knowledge gap, thereby, aiming to create theoretical models of this concept. Therefore, the core nature of this study is conceptual. Relevant secondary data is drawn from the existing literature in the form of numbers and graphs to quantitatively establish the state of each of the three sectors before being joined together into a new nexus called Waste to Energy for Transport and abbreviated as WET Nexus. An account of challenges as well as benefits is outlined regarding the possibility of replacing the consumption of fossil fuel by waste-to-energy i.e. a kind of 'on-board' waste incineration to propel maritime vessels and also supply energy to 'on-board' built environments. Thus, killing two birds (transport and waste) with one stone (energy). The paper also touches upon innovative insights and future research potentials in terms of how maritime transport being driven by energy-from-waste instead of fossil fuels, can improve environmental sustainability; help climate emergency agendas and; also contribute to the Climate Action, which is one of the seventeen SDGs (Sustainable Development Goals) introduced by the UN (United Nations).

KEYWORDS*: Waste to Energy (WtE), Energy from Waste (EfW), Maritime Transport, Waste Management, Climate Action, Climate Emergency, Environmental Sustainability.*

1.0 INTRODUCTION

1.1 Background

The notion that any human activity should be sustainable, probably has been accepted as a basic premise, though this realization should have been much faster than it has been. Among the various factors influencing the environment of our planet, exponential increase in human population has always been at the top of the tiers. Two of the main anthropogenic influences are transport and waste. However, all anthropogenic activities involving the use of resources – soils, minerals, environmental aesthetics, or finite fossil fuels – cannot continue forever (Heinberg, 2010), and it is necessary to manage resources within their regeneration capacity. This means that resources should be used carefully in every sector, industry rather every walk of life.

Among several energy consuming sectors, the transport is the prominent one. Energy consumption for both travel and freight movement has rapidly been growing (Rashid, 2019). It is estimated that tranportation energy consumption would increase by nearly 40% between 2018 and 2050. Thereby, this sector is placing considerably an additional strain on fossil fuel reserves (Gracia et al, 2018). The question arises that how the transport sector can be decarbonized in terms of replacing fossil fuels by non-fossil fuel resources. Another question is that the fossil fuel of which transport mode can be replaced by which type of non-fossil fuel with what environmental, climate change and sustainability implications. Such research questions or arguments have been substantiated by referring to various literatures in Section 3.1 and the overall problematization scope of this study is contained in Section 1.2 below.

On the other hand, the production of municipal solid waste (MSW) – constituted as quotidian waste – and commercial waste (CW) and industrial waste are continuously on the rise as areas become more industrialized and urbanized. It was estimated that average annual global waste produced in 2012 was 1.3 billion tons and is predicted to still increase by almost 60% i.e. 2.2 billion by 2025 (Hoornweg & Bhada-Tata, 2012). In the waste management industry, the sustainable waste hierarchy is a fundamental benchmark, according to which, landfilling is the least preferred option and waste-to-energy is relatively more preferred option (i.e. incineration). But majority of the waste is still landfilled for it is still the simplest way most of the times. However, the technologies and techniques regarding waste incineration to reduce the volume and yet recover energy/power from that waste have been considerably improving.

From the above description regarding transport and waste it can be seen that the energy is a common denominator, however the former requires the energy to operate while the latter would yield energy if incinerated. Thus, the output of energy in waste incineration can be channelled into the transport sector. That is like killing two birds (transport and waste) with one stone (energy). The coupling of the two sectors (i.e. transport and waste) via energy is what this study focuses on.

1.2 Problematisation and the Research Aim

No evidence has been found in the review of literature regarding the idea of tying the two sectors (waste and transport) together via the thread of energy and yet expressed in the form of a nexus. There are additional contemporary implications which do not seem to have been considered regarding this venture for this is being introduced for the first time in the form of a nexus. Examples of such implications include: environmental benefits (in the three main spheres of the total environment i.e. atmosphere, hydrosphere, and lithosphere), technical challenges (e.g. logistics), technological limitations, economic viability, and alike. Similarly, the venture can potentially be linked with which directly relevant SDGs (Sustainable Development Goals) and how it can assist to overcome climate change challenges and yet to what extent (UN, 2020; 2021). It is also necessary to establish the pragmatism of this venture in various modes of the transport that is, terrestrial (road), aviation (air), and maritime (water).

Business as usual is not sufficient to deliver sustainability at any levels of the human society, from neighbourhood through local, regional, national, continental to global. New ventures, widely inclusive partnerships, and innovative ideas are required more than ever before to be explored in order to more productively thrust the agendas of sustainability and climate change at national and international levels (Scheyvens et al, 2016; UN, 2014).

The purpose of this research study to not only examine the innovative idea in its own right as a possibility, but its multifaceted aforesaid implications are also outlined in order to briefly project the potential to employ waste-to-energy option to run the maritime transport. The study also torches light on some limitations with the other two modes of the transport – terrestrial and aviation. In addition, the study creates a brief account of benefits and challenges of this innovative notion while conceptually viewing through the lenses of the climate change impacts and the sustainability philosophy. The scope of the paper is to formulate the innovative nexus and only conceptually link with various environmental, sustainability and climate change aspects. The study does not aim to include thorough particulars on such linkages as paper is to cover more of the 'breath' and less of the 'depth'. However, still several avenues for further research are indicated as examples which the study brings out, though without much details due to the nature and brevity of the study.

1.3 Concept Development Strategy

Following on from the aforesaid research study purpose/aim, this study is 'transdisciplinary' in its nature which combines the three different sectors to produce an innovative concept of WET – Waste to Energy for Transport – Nexus. Therefore, each sector, first, is captured individually as in its own right. For this purpose, the state of each sector is established based on secondary data regarding that sector. In addition to qualitative/descriptive expressions, the secondary data is also presented numerically and graphically, as appropriate, to quantitatively articulate the significance of each sector. The three 'leads', one from each sector, are brought to the main point where the three sectors are integrated or combined together. This amalgamation of the three sectors is with the idea of theoretically framing a nexus as well as associated implications via presenting with schematics in the form of conceptual models. Therefore, the fundamental nature of this study is conceptual in which models are theoretically conceived and developed based on existing literature and knowledge gaps (where the main gap is the integration of the three sectors in such an innovative way that they feed off each other, and yet directly). Furthermore, the study also outlines the potential benefits of the nexus by briefly relating it with environmental implications, climate change challenges and sustainable development philosophy, as in SDGs (Sustainable Development Goals) introduced by the United Nations (UN) in 2015 (UN, 2020). However, it must be noted and an exhaustive account of the aspects of the nexus relationship with the environment, climate change and sustainability, is not in the scope of the study. The main notion or idea of the study is to conceive, design, develop, and present a conceptual model of the nexus and only briefly outline potential benefits it can bring about. These potential benefits, however, may be unlocked with further research works. In other words, the study is more inclined towards being more cross-sectional and less longitudinal, out of which several longitudinal research works can off-shoot in future. The fundamental approach of the study, therefore, is to theoretically paint a holistic view of the innovative subject matter that is being introduced for the first time by the paper in the form of the WET Nexus.

2.0 STATE-OF-THE-ART

2.1 Transport in General

Transport modes are essential components of transport systems since they are the means by which mobility is supported. Modes can be grouped into three broad categories based on the medium they exploit: land, water, and air (Figure 1). Each mode has its own requirements and features and is adapted to serve the specific demands of freight and passenger traffic. (Agriculturist Musa, 2018; Saloodo, 2020):

1. *Terrestrial/Road transportation:* involves moving passengers and freight with vehicles over a prepared surface and further expands into:

    - Roadways: automobiles provide high flexibility with low capacity, but require high energy.
    - Railways: railed vehicles move with much less friction than rubber tires on paved roads, making trains more energy efficient, though not as efficient as ships.

2. *Aviation/Air transportation:* is the movement of passengers and freight by any conveyance that can sustain controlled flight*.* Aviation is able to quickly transport people and limited amounts of cargo over longer distances, but incurs high costs and energy use.

3. *Maritime/Water transportation:* concerns the movement of passengers and freight over water masses, be it in oceans, rivers, lakes and alike (Jean-Paul, 2020). Transport by water is significantly less costly than air transport for transcontinental shipping. Although it is slow compared to other transport, modern maritime transport is a highly efficient method of transporting large quantities of goods.

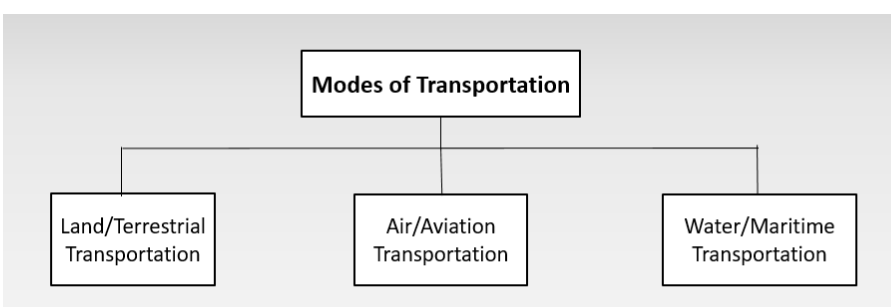


Figure 1: Modes of Transport.

2.2 Maritime Transport

Demand for maritime transport continues to grow rapidly. Maritime transportation drives 80–90% global trade, moving over 10 billion tonnes of containers, solid and liquid bulk cargo across the world's oceans annually (Ashrafi et al, 2019; Schnurr & Walker, 2019). The industrial revolution further improved ship transportation by capitalizing on the capabilities of internal combustion engine-power, and the subsequent adoption of containerization once again dramatically changed maritime transportation in the name of efficiency. Although a relatively "hidden" part of global society, maritime transportation is imperative to continued global development. Given the intensity of globalization and its ability to connect and disperse, maritime transportation continues to account for the majority of imports and exports for nation-states large and small, and continues to underpin all regional trading systems (UNCTAD, 2018). Existing maritime transportation fleets using bunker and heavy fuel oil are being phased out and replaced with new ships powered by low-carbon fuels. But this option still not be considered. Transportation activities are important consumers of energy for the purpose of providing mobility to passengers and freight, which accounts for about 25% of world energy use (Schnurr & Walker, 2019).

2.3 Waste Production and Management

Waste generation is a natural product of urbanization, economic development, and population growth (Kaza et al, 2018). In the past century, as the world's population has grown and become more urban and affluent, waste production has risen tenfold (Hoornweg et al, 2013). Simply, around the world, waste generation rates are rising. In 2016, the worlds' cities generated 2.01 billion tonnes of solid waste, amounting to a footprint of 0.74 kilograms per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 70% from 2016 levels to 3.40 billion tonnes in 2050 (Kaza et al, 2018). Figure 2 refers that most of waste residing on our planet is being generated from Asia and European regions of the world. Central Asia, South and East Asia, Europe and Pacific regions are main contributors of the waste generation around the world (Economist, 2018; Kaza et al, 2018)

Emerging economies are rapidly adding to the global pile of garbage (Piotrowski, 2018). Compared to those in developed nations, residents in developing countries, especially the urban poor, are more severely impacted by unsustainably managed waste. In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned (Kaza et al, 2018). These practices create serious health, safety, and environmental consequences (Hoorenweg & Bhada-Tata, 2012). Poorly managed waste serves as a breeding ground for disease vectors, contributes to global climate change through methane generation, and can even promote urban violence. Managing waste properly is essential for building sustainable and livable cities, but it remains a challenge for many developing countries and cities (Chung et al, 2002).

The majority of all types of refuse is still disposed of at landfill, regardless of whether the waste can be re-used or not (Bovea et al, 2016). This creates further environmental issues, such as water and land contamination, along with methane gas being produced during decomposition at landfill. This form of waste disposal is the least desirable method of waste management because of its adverse environmental impacts. For example, the landfills take up space that could be used for more beneficial constructions, like housing, and interrupt the natural habitats of organisms nearby. Because of this, landfilling is unsustainable due to the limited supply of land that is available globally (Williams, 2007). The decomposition of waste in landfill generates products in all the three states a matter can exist in, i.e.

landfill leachate (which is a liquid); landfill gas (which predominantly contains carbon dioxide and methane – both are greenhouse gases – GHG) and more or less degraded waste which causes subsidence of the land (Ritzkowski & Stegmann, 2007; Butt & Oduyemi; 2003; Butt et al, 2008; 2011). Moreover, the degradation process in landfills can last from weeks through to hundreds and even thousands of years depending on waste type. For instance, Aluminum cans would take between 80-100 years for complete decomposition. Disposable diapers take between 250 and 500 years to decompose in landfills. Plastics, while we interact with them in practically every aspect of our lives ranging from plastic bags to the hardest plastic we know, plastic products are the most polluting products in existence. When buried, they can take up to a thousand years to decompose while some types of plastics actually may never decompose (WAM, 2017; WorldAtlas, 2021).

Furthermore, the landfill option of waste disposal disregards the potential to harness the remaining potential energy within the litter and so the rate of resource depletion will be increasing as we continue to extract energy from new reserves of non-renewables, despite being equipped with an array of materials that can be used in energy recovery. By waste-to-energy practice in incinerators, the life of global fuel reserves could be prolonged (Cohen-Rosenthal & Musnikow, 2017).

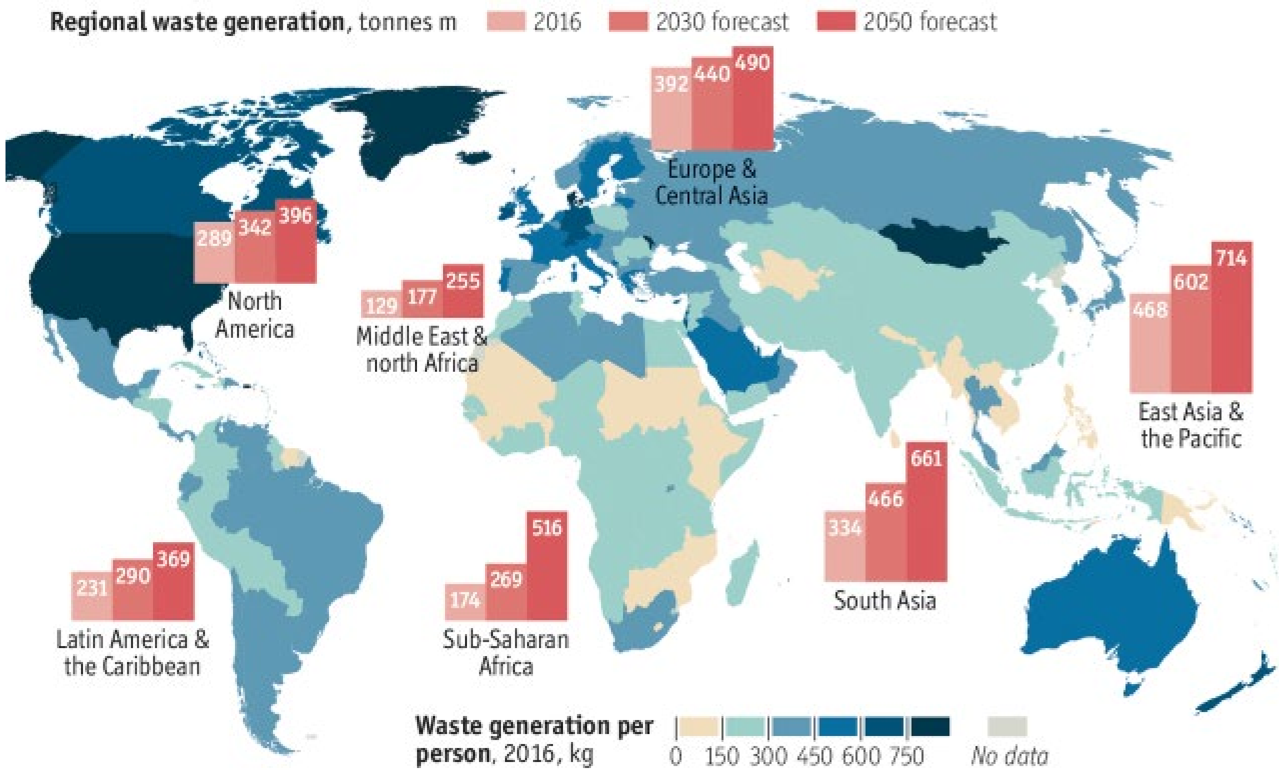
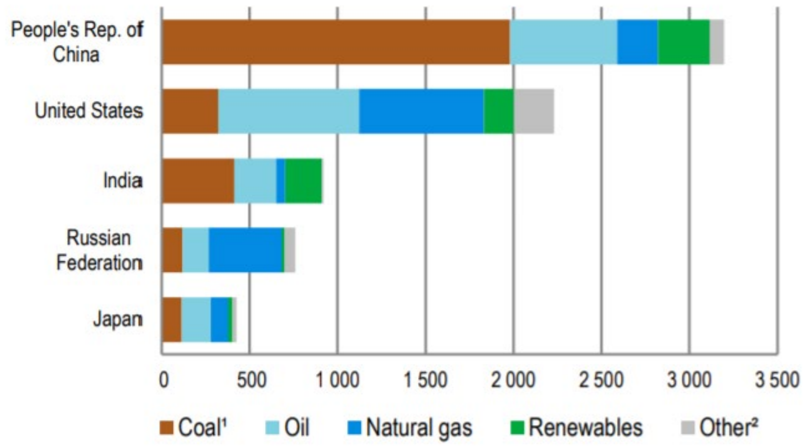


Figure 2: Regional waste generation (Source: The World Bank – Kaza et al, 2018)

2.4 Energy Perspectives

Fossil-fuels are the predominant sources of energy generation worldwide, where roughly 86% of global energy consumption can be attributed to sources such as: oil, natural gas, and coal and correspondingly the fossil carbon emissions have been on the increase, overall (regardless of COVID-19 has slowed down it a little most recently) (BP, 2017; Rashid et al, 2019; UN, 2020; Bertram et al, 2021; Le Quéré et al, 2021). Furthermore, the total energy demand is projected to increase in response to the growth in population. However, with continuous usage of said resources, the reserves of these combustibles are nearing depletion where they cannot be renewed (Dufour, 2018). This means a substitute for energy generation is required to reduce the strain on these reserves and mitigate the fuel crisis in order to achieve a sustainable future.

From Figure 3, it can be seen that the primary source of energy is abstracted from non-renewables - in particular: coal. The calorific values for the fossil fuels shown above yield higher energy values (ranging from 29-50 MJ/kg from coal to natural gas) which makes them prime sources to meet the energy demands worldwide (EIA, 2016). In terms of potential energy to be released / generated from a source, renewable methods – such as turbine and solar – usually have lower yields than that of fossil-fuels (Moriarty & Honnery, 2016). This is a large factor as to why the changing of primary fuel sources is slow; current sources of sustainable energy cannot meet the entire energy demand, thus combustibles like oil are still in use as they provide sufficient amounts of energy to power the devices that utilise them e.g. aircraft, automotive, etc. The worldwide dependency on unsustainable fuels is highlighted in Figure 3.



[1]In this graph, peat and oil shale are aggregated with coal.
[2]Other includes nuclear, electricity trade, heat, non-renewable waste.

Figure 3: Top 5 energy consumers by region, and proportion of energy sources used (IEA, 2020)

Referring to Figure 4, the usage of energy can be categorized into different sectors, including: commercial, industrial, residential, and transport. The transport sector roughly attributes to one fourth of the energy usage and can reach higher demands depending on the region.

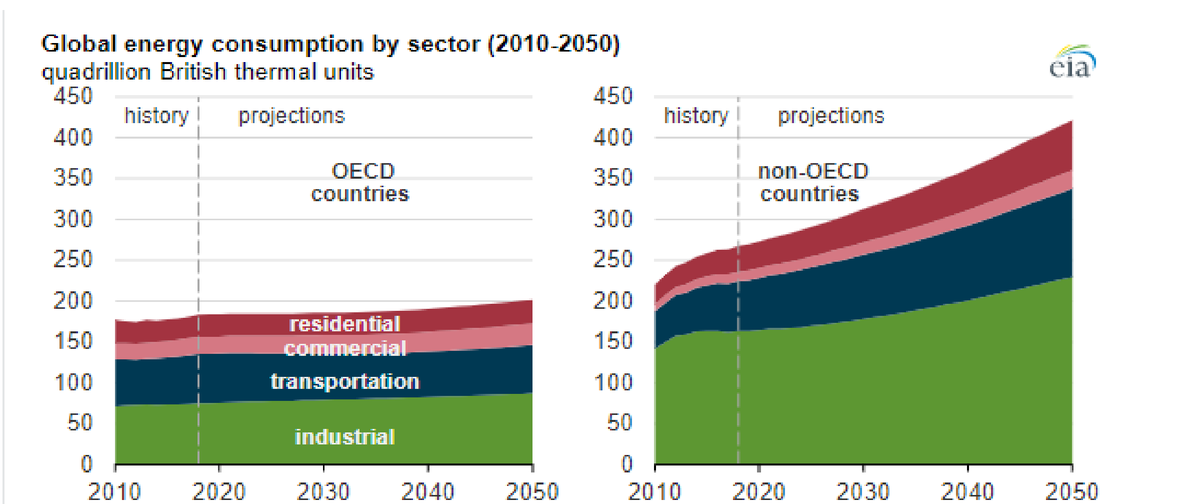


Figure 4: Global energy consumption by sectors (EIA, 2019)

The transportation sector is the second-largest user of energy (Figure 4). More than half of the energy used by the transportation sector is in nations belonging to the Organization for Economic Co-operation and Development (OECD). However, transportation in non-OECD nations is expected to dominate future growth in fuel use (EIA, 2009).

2.5 Global Waste-to-Energy Market

According to the Global Waste to Energy Market Analysis (2020), research report, market size of Waste to Energy market across the globe is predicted to grow at the CAGR (Compound Annual Growth Rate) of around 6% during 2020-25. It is estimated that the global waste generation would increase by 3.40 billion metric tons by 2050 in comparison to 2018 (Kaza et al, 2018). The main key factors sharing to the market growth of waste-to-energy market include: the incipient need for reducing the volume of waste generated from the municipal, industrial, and agriculture sectors; growing urbanization; extravagant industrialization; and surging population across the world would supplement the waste generation, consequently, increasing the imminent need for energy in the market (Rogers, 2006). Therefore, the advancement in the growth of waste-to-energy market in the coming years is expected.

The governing bodies of various countries in the world have announced their strategies to optimize the use of non-fossil fuel energy means (Huaman & Jun, 2014), because of which, the market size of waste-to-energy market can further upsurge. For instance, Europe, being an established market for the progression of waste-to-energy solutions, achieved the major market share in 2019. For 2019, the region had about 500 waste-to-energy plants which convert the millions of tons wastage into energy (Mubeen & Buekens, 2019). Furthermore, the technical advancement in the waste-to-energy solutions could contribute to the rising market share of the region. However, the APAC (Asia-Pacific) is anticipated to behold a robust growth during 2020-25 due to the increasing investment in R&D (research and development) by the countries such as China and Japan for the treatment of solid waste Furthermore, the rising number of Waste-to-Energy plants in the developing countries is contributing to expand size of waste-to-enenrgy market. Additionally, the governments' aim to reduce carbon footprints in energy production and to stop the usage of coal in the power generation would actively contribute to the increasing size of waste-to-energy market in the forecast period of 2020-25 (GlobeNewswire, 2021). The already esclating market of waste to energy can be accelerated even further by exploiting its potential in conjuction with the transpot sector as described in the section 3.0.

3.0 INNOVATIVE INSIGHTS

3.1-Waste-Energy-Transport (WET) Nexus

Due to escalating demand of energy in the transport sector, switching transport to renewable energy systems has increasingly been becoming a priority, for both passenger and freight transport. This also means a substitute for energy generation is required to reduce the strain on fossil fuel. On the other hand, elevation in the quantity of waste due to ever increasing commodities (both in numbers and types) is likely to continue to result in an increase in landfilling in different parts of the world, as the majority of MSW and CW is not currently reprocessed effectively. However, it may be possible to use waste more sustainably by employing waste-to-energy option directly into the transport sector i.e., Waste (W) to Energy (E) for Transport or Transportation (T) which this paper introduces as the WET Nexus concept. This innovative idea is schematically presented in Figure 5 in an input versus output format, while Figure 6 captures the idea in the form of Venn diagrams. In Figure 6 there are three sub-figures. The first sub-figure presents the multi-disciplinarity aspect of the Nexus, while the second one shows the inter-disciplinarity.

The third sub-figure demonstrates the trans-disciplinarity nature of the Nexus which connotes the research strategy of crossing a number of disciplines to create a holistic approach. The third sub-figure captures this as follows: waste is burnt/incinerated (in the outer most circle) which results in energy (the middle circle) and eventually, this energy is channeled into the inner most circle that represents the transport sector to be powered by this energy.

While a wide range of literature is reviewed, no evidence of such a nexus idea is found in the literature to date which states that the energy produced from waste incineration can be used to 'propel' the 'means of transport'. Some literatures focus on waste to energy via gasification alone and the connectivity with the transport is not to channel energy to move the means of transport but transporting waste to the gasification and incinerator plants (Liu et al, 2021). Some literatures concentrate on waste, energy and even transport implications but in urban contexts. However, still the transport is addressed with the idea of carrying the waste around and not to propel the means of the transport at all (Taskin and Demir, 2020). Some literatures present models on urban systems in which energy and matter/materials are considered as inputs to the system, waste and emissions as outputs from the system, and transport as an internal item of the urban system. However, the combination of waste to energy for transport is not in the scope of such urban models despite being widely holistic (Alberti, 1996). Similarly, there is substantial amount of literature on greenhouse gases (GHG) emissions in connection to energy usage in and carbon footprint of the built environment and the transportation sector, but the waste is excluded altogether (Getvoldsen et al, 2018; Pan et al, 2020a; 2020b).

Some literatures would consider only on one of the three items of the WET Nexus and the remainder two would not be in the remit at all. For instance, some literatures do not include waste and transport as such, but only energy from the perspective of renewable resources and carbon emissions (Qerimi et al, 2020).

Similarly, there are literatures on energy management systems in various contexts, for example, optimisation even via hybridising renewable and non-renewable energy resources such as solar, wind, batteries and diesel (Tahiri et al, 2021) while waste and transport are not included at all. Also, there are literatures which would focus only on the waste element of the nexus and the other two are totally excluded. For instance, Khan et al (2020) is regarding marble waste conversion into a binding material with financial and environmental benefits. However, neither energy nor transport are in the scope of this study. In summary, different literature have considered waste, energy and transport either individually or in varying combinations to different extents in various contexts, and the extremely few ones who dwell on all the three of them, still do not consider energy from waste to power the means of the transport in the form of the WET nexus (UN, 2014).

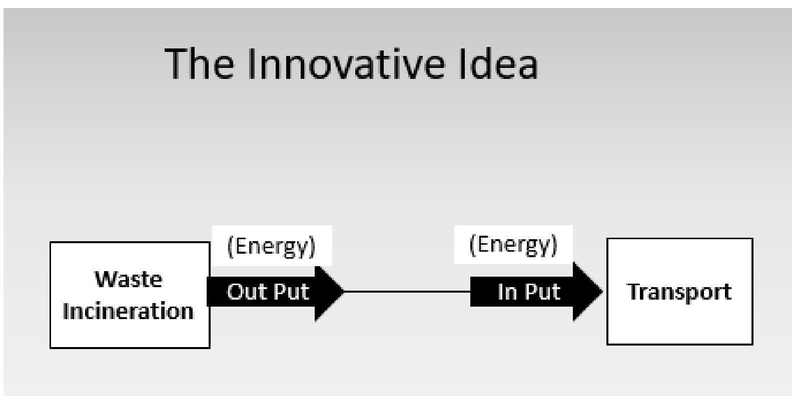


Figure 5: Relationship of waste and transport via energy

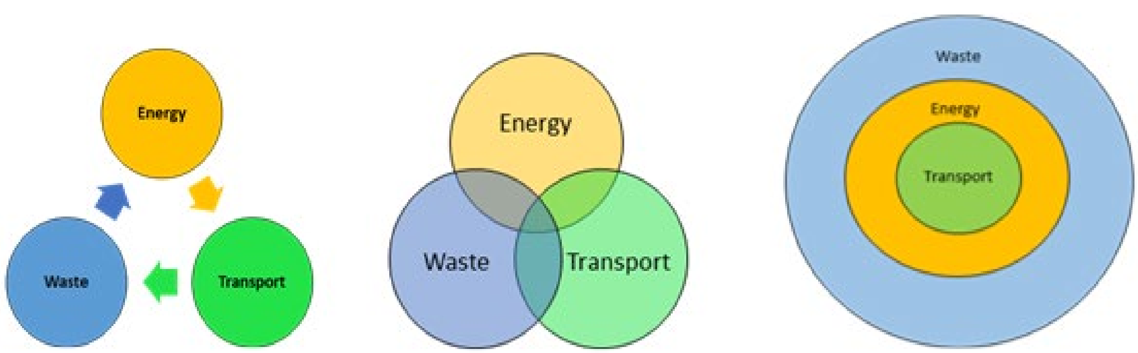


Figure 6: Waste-Energy-Transport (WET) Nexus

3.2 Waste Incineration versus Fossil Fuels

Unlike fossil-fuels and other mainstream energy sources, the calorific values of MSW and commercial waste tends to be lower, yet their accessibility is what makes them desirable in this context. MSW consists of the typical domestic waste produced in a household environment, such as paper, plastic, cardboard, food, etc. (Hoornweg & Bhada-Tata, 2012). Commercial waste involves the waste produced from business. Usually, the two categories overlap, where CW is mainly composed of packaging materials, like paper and cardboard. All materials possess a calorific value (CV) which equates to the amount of energy released from a set amount of the said material after complete combustion (Lupa et al, 2011). Typical MSW's net CVs range from 4 to 35MJ/kg from organic materials to certain plastics (WEC, 2016a; 2016b). Although these values are lower than that of fossil-fuels, they can still be beneficial in partially powering systems on a maritime, such as heating arrangements, lighting, and domestic electrical outlets.

Figure 7 shows that the majority of the transport sector's power is met by fossil fuels. This set to increase by around 30Btu between 2020 to 2040. By partially substituting the burning of the oils and gases for that of the incineration of detritus (waste-to-energy), the energy released can be used to power maritime transport in a hybrid technology. The WET Nexus idea suggests an onboard incinerator on the maritime, where the detritus is directly combusted. The idea behind targeting the maritime transport is that the incinerator requires for waste incineration is so large in size that only gigantic maritime vessels would be more able to accommodate it. More details in the following paragraphs.

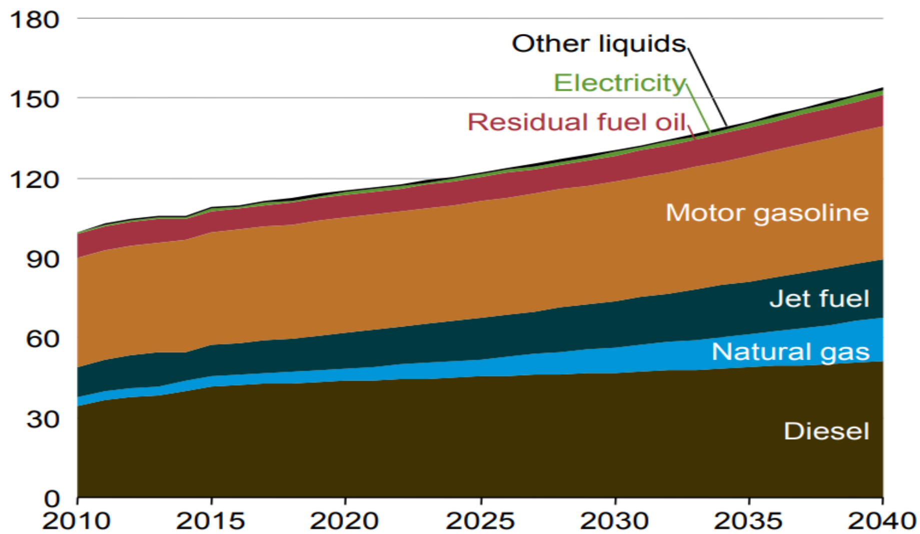


Figure 7: Global transportation sector delivered energy consumption by energy source, (quadrillion Btu) (EIA, 2016)

In 2019, the thermal technology dominated the global waste-to-energy market and is expected to continue its dominance in the forthcoming years owing to the increasing demand for incineration technology in the developing countries (GlobeNewswire, 2021). Incinerators reduce mass of the solid waste by 80% –85% and volume of the waste by 95% – 96%. Upon incineration (a typical process of which is shown in Figure 8), the heat generated could be used in heating the maritime vessels HVC (Heating Ventilation and Air Conditioning) in a Combined Heat and Power (CHP) technique. The overall efficiency of the process will be improved in doing so, as using incineration to only produce power will yield 15-27% efficiency, ameliorating the process by up to 25% (WEC, 2016a). The onboard incinerator, in terms of power generation, could be used to drive a turbine and store the electrical energy conducted for future use in the form of a battery. Waste-to-energy plants/incinerators can be innovatively applied on the maritime vessels. For instances, we can have extra diesel engine, windmills technology, some incinerators can be supplemented by electrically driven heat plates and exchanges to boost the heat generated, these can be powered by solar. In this way, can offset peak demand and reduced the amount of heat that needs to be generated by incineration, thus better controlling emissions. Alternatively, the process could be done similar to that of a steam engine, where steam produced could be used to directly propel the vessels, however, this would involve a more vigorous redesign of maritime vessels.

Incineration requires a sufficient, continuous flow of oxygen, and a typical combustion temperature in excess of around 850°C. The onboard incinerator could be designed with various technologies in-mind, such as moving grate designs or utilising a rotary kiln (DEFRA, 2013). In this case, a moving grate design would be sufficient in transporting the waste from its reserve to the maritime to be burnt. At each depot, stores of waste could be situated for constant refueling to ensure that there is a satisfied amount of fuel to power the system

However, economic expense of incineration can be large, and gaseous emissions that contribute to climate change and health risks are still released. These include but are not limited to: styrene vapour; polychlorinated biphenyls; mercury vapour; carbon dioxide; sulfur dioxides; nitrogen; etc. (Hussain et al, 2019). So, while landfill takes up land and does not utilise the disposed waste, incineration directly releases pollutants that can be damaging to public health. However, this can be mitigated with filter treatments that capture the particulates released during combustion, filtering the gases released to reduce carbon emissions.

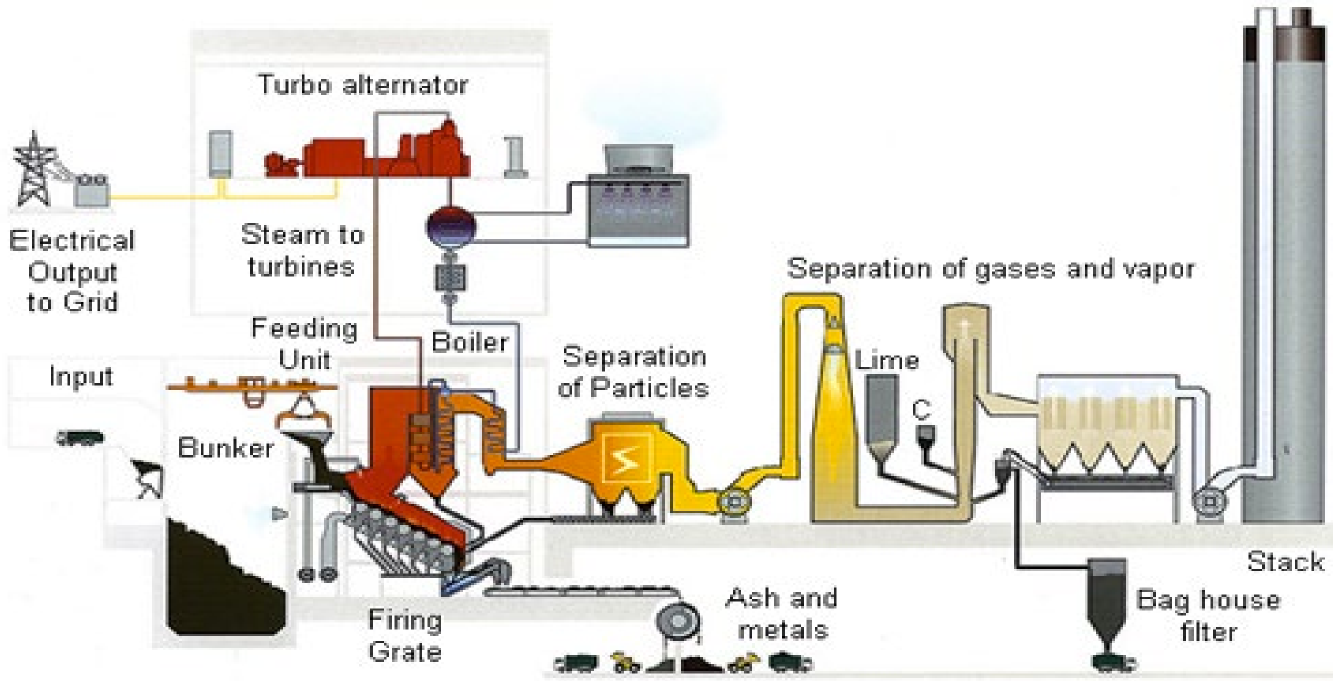


Figure 8: A typical waste incineration Plant (Burruss, 2013)

3.3 Sustainability and Climate Change

One of the attractive aspects of the WET Nexus is that the production of waste is continuous, thus the source of it would be plentiful. This would also reduce energy wastage due to line losses because the energy generated at the source through incineration of the waste onboard of the vessels will be consumed within the vessels as opposed to terrestrial waste-to-energy scenario in which incinerator plants can be miles away from the city to which the energy would be supplied through grid and power line. Furthermore, the waste is generated in large amount in correspondingly big cities which generally sit near by large water bodies such as estuaries and the sea e.g. London, Karachi, Mumbai and alike. The large amount of waste from such cities can be easily and effectively transported to harbors/maritime vessel instead of being carried into the land across large distances for suitable landfill or incineration sites. This technology may make it possible to look to waste products to partially fund certain sectors, particularly due to the increasingly excessive amount that is being produced globally. In addition to generating energy for transport, the process also reduces landfilling by reusing the waste that would be managed in this way and the strain placed on fossil-fuel reserves could be mitigated by a small extent, depending on the volume and type of waste used. Ensure sustainable energy production and consumption patterns.

The nexus would help to enhance the environmental sustainability management of wastes in a number of ways. For instance, having less number of landfills and waste incineration in land would significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment. By paying special attention to municipal and other waste management, it would reduce the adverse per capita environmental impact of cities. Reduction in landfilling would enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management.

From the perspective of climate change implications, one of the reasons for climate change acceleration are anthropogenic activities leading to greenhouse gases (GHGs) emission. Among these GHGs, carbon dioxide is produced in most abundance owing to fossil fuel combustion for power and methane (which is tens of times more greenhouse effective than carbon dioxide) produced from biodegradable landfills in particular. The WET nexus idea can constitute to reduce these gases directly, thereby contributing to various regimes of climate change mitigation – climate action, climate emergency and other such agendas and policies be it national, regional, continental or global. Moreover, the nexus can also lessen the transport of waste (particularly in large coastal civilizations / cities) up in the land direction via the terrestrial mode and, thereby, lower the associated fossil fuel consumption and greenhouse gas emissions. This can further assist in delivering the climate action which is one of the seventeen SDGs

(Sustainable Development Goals). The nexus can also improve air quality/atmosphere and reduce acid rain which would additionally lessen adverse impacts on the built environment/anthroposphere, land/lithosphere and water/hydrosphere. Thereby, directly help with the SDGs which specifically regard air, water and land.

4.0 DISCUSSION AND CONCLUDING REMARKS

Currently, the study presented in this paper is only conceptual at this stage. This paper considers amalgamation of two main sectors from the anthroposphere, which are transport and waste. Initially, the two sectors are individually discussed, then followed by the context of energy as a possible thread that can potentially combine or 'tie' the two sectors together. It is established that one sector can generate energy (i.e. the waste sector) via incineration and other the sector can consume energy (i.e. transport) directly in order to propel the means of transport. Therefore, the paper innovatively connects both the sectors via energy being a common denominator. This is referred to as a new (conceptual) integration of Waste to Energy for Transport, the WET Nexus. Moreover, this study introduces WET nexus as a 'Trans-disciplinary' subject matter in which the three different sectors are assembled. Thus, it is also multi- and inter-sectorial on the top of multi-, inter- and trans-disciplinary.

However, while there are three basic modes of transport i.e. land/terrestrial, air/aviation and water/maritime, the third mode appears to be more promising due to physical limitations such as the size and weight of WtE power plants. In other words, though waste-to-energy as an 'onboard incinerator' in transport is relatively yet another new concept, the practicality of this seems to be more feasible in the maritime transport rather than the other two modes. In this connection, however, no real or model data exists in the literature specific to the WET nexus, as the nexus is being introduced for the first time as a new concept via this paper.

This study also highlights a number of potential benefits of the waste-energy-transport (WET) nexus, particularly in connection to the maritime transport. Channelising the waste-to-energy towards the maritime transport, would reduce the number of landfills and 'on-land' waste incineration thereby, improving air quality nearby human settlements – a matter of environmental health and subsequently human health. This would also reduce the probability of acidic rain. In addition, as opposed to static, on-land WtE (waste to energy) power plants, the mobile WtE plants on maritime vessels means that the flue gases would be automatically diluted/diffused as the vessel sails in the sea. Thus, fewer landfills and less use of fossil fuels would assist to reduce GHG emissions into the atmosphere. This would result in less acidic rain which would also mean cleaner land/soils and surface waters, as pollutants travel between atmosphere/air, hydrosphere/water and lithosphere/land or soils. This cumulative, collective, and holistic picture of multi-advantages is schematically expressed via Figure 9 below. Furthermore, less landfilling means less risk of methane emissions whereas methane is a powerful greenhouses gas with a 100-year global warming potential 28-34 times that of carbondioxide and if measured over a 20-year period, that ratio grows to 84-86 times (UNECE, 2021). Thus, the Nexus idea can be a direct contribution to decelerate global warming, which is one of the biggest manifestations of climate change. In this way, the WET nexus can also offer a contribution to mitigation measures against climate change.

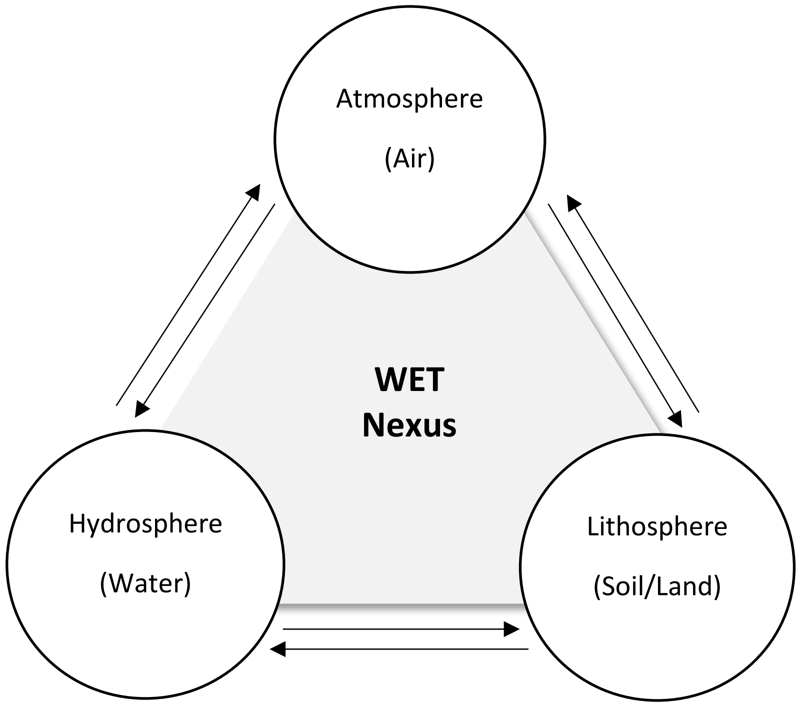


Figure 9: Multi-dimensional engagement of the WET Nexus with the Total Environment

For the WET nexus being multi-dimensionally engaging with the total environment, the nexus also has great potential to enhance environmental sustainability; inform the climate change agenda; and contribute towards SDGs. The main SDGs to which the Nexus can potentially contribute, directly or indirectly, fully or partly, include: Climate Action, Clean Water, Clean Energy, Innovation and Infrastructure, Life on Land, Life below Water and, Sustainable Cities and Communities. A conceptual schematic which categorically reflects on the possible advantages of the WET Nexus is presented in Figure 10 below.

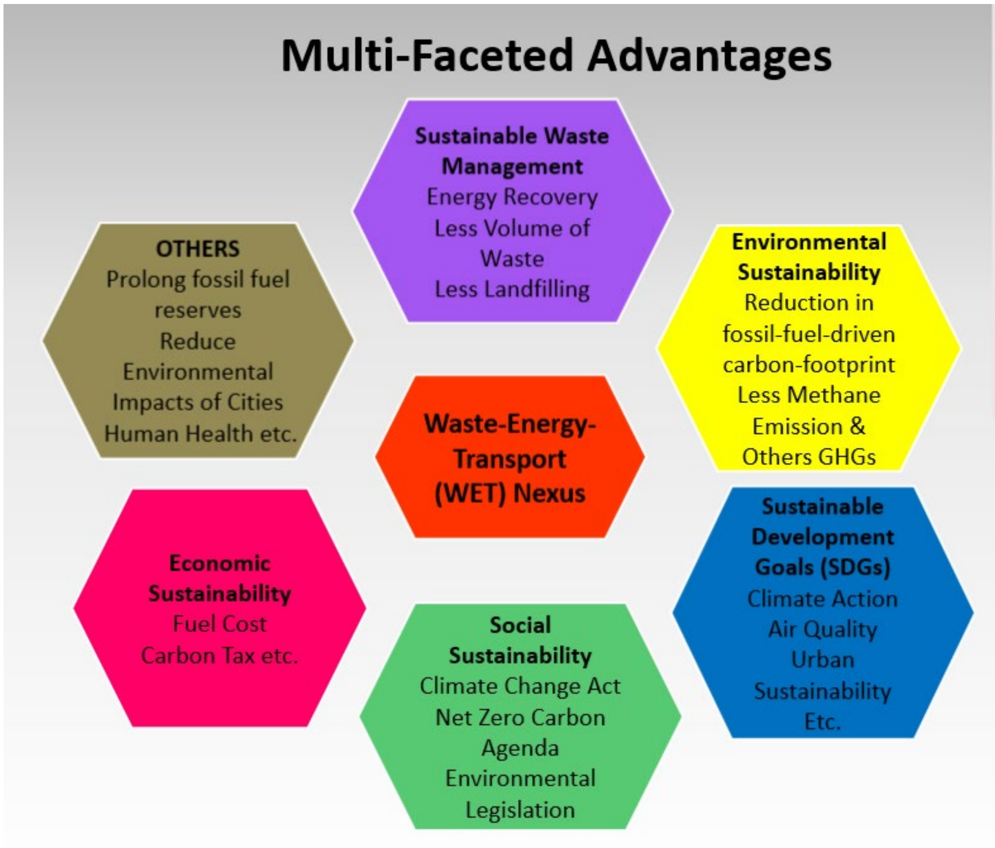


Figure 10: Hexagonal model of multifaceted advantages of WET nexus

5.0 LOOKING AHEAD

This conceptual research paves a path on a number of fronts. Some examples of which are as follows: Numerical estimation models can be developed to establish the potential of unlocking the advantages of this nexus at local, regional, national, continental and international levels. Some studies can also be carried out regarding the infrastructure feasibility involving e.g., waste collection; waste contamination; waste segregation (especially between combustible and non-combustible materials) in terms of good calorific value; transfer stations at harbors; boarding waste on maritime vessels; waste odour control for social acceptability or social sustainability, and alike. The innovative nexus would also need to be investigated in view of existing legislative instruments and that what kind of future legislation may be required specifically in association with this.

Some technical studies may also be required in terms of typical, fossil fuel driven power engines being replaced by waste incineration engines not only to propel the maritime vessels but also to operate the on-board built environment functions such as cooling, heating passenger's carriages, lighting, cooking, air-conditioning, moisture control and other appliances. Thus, incineration plants' design, manufacturing, and installation specifically for sea-vessels / ships to incinerate waste onboard to generate energy, itself would be an area of further research and development in its own right. In the environmental sustainability context, the carbon footprint control technologies such as Carbon Capture and Storage (CCS) can be applied. Similarly, Combined Heat and Power (CHP) plant may also be considered to harness the heat of the flue gases and outweigh the extra energy that is required to operate the CCS technology (Butt et al, 2012). The ashes from the onboard waste incineration can also be reused in the construction industry as main or filler materials, as appropriate.

From terrestrial transport perspective, batteries could be charged at the Waste to Energy power plants and supplied to fuel (existing gas/petrol stations) for electrical cars and busses. Like cars and busses refuel with fossil fuels at gas/petrol stations, electrical cars and busses can simply drop the used batteries at the station and collect the fully charged ones. However, this would need research and development not only for designing easily replaceable electrical batteries for cars and busses, but also the existing infrastructures would require to be adapted/upgraded for this approach to work. In summary, this research study while is conceptually depicting the three sectors can feed into each other, can potentially lead to a much wider socio-economic and environmental benefits and challenges, thereby sets up a new platform for more innovative technologies and techniques to come into being.

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