VISION

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Foreword from ISSE- KKC President

Dear Colleagues,

Greetings and hearty wishes to members of ISSE- KK chapter. It is my immense pleasure to introduce this maiden e-magazine namely "Vision - ISSE KKC" to you all. It is the vision of ISSE-KK chapter to share knowledge among members about system engineering and to create awareness about recent trends and technologies. This e-magazine is regarded as a launch pad for broadening horizons and exchanging ideas. The launch of this e-magazine marks yet another step taken by the society in the dissemination of information among members collectively from various fields namely research and development, academia and so on. It gives ample opportunity for eminent personalities and experts of various fields to share their expertise and get mutually benefitted. I wish once again a grant success for Vision - ISSE-KKC and the ray of light may enlighten young minds.

J. Asir Packiaraj,
President, ISSE, Kanniyakumari Chapter/
Associate Director, IPRC

Topics presented:

1) Systems Engineering: Historic and Future Challenges
2) System Engineering challenges in designing a ignition systems in liquid rocket engines
3) The new wonder material – Borophene
4) Hydrogen based Vs battery-based transportation systems

1) Systems Engineering: Historic and Future Challenges

Author: Mr. B. Gouri Shankar, Manager, Cryogenic facilities-Safety, ISRO Propulsion Complex (IPRC)

Humans have faced increasingly complex challenges and have had to think systematically and holistically in order to produce successful responses to these challenges. From these responses, generalists have developed generic principles and practices for replicating success. Some of these principles and practices have contributed to the evolution of systems engineering as a discipline.

Some of the earliest relevant challenges were in organizing cities. Emerging cities relied on functions such as storing grain and emergency supplies, defending the stores and the city, supporting transportation and trade, providing a water supply, and accommodating palaces, citadels, after life preparations, and temples. The considerable holistic planning and organizational skills required to realize these functions were independently developed in the Middle East, Egypt, Asia, and Latin America.

The Industrial Revolution brought another wave of challenges and responses. In the nineteenth century, new holistic thinking and planning went into creating and sustaining transportation systems, including canal, railroad, and metropolitan transit. The early twentieth century saw large-scale industrial enterprise engineering, such as the Ford automotive assembly plants.

The Second World War presented challenges around the complexities of real-time command and control of extremely large multinational land, sea, and air forces and their associated logistics and intelligence functions. The post war period brought the Cold War and Russian space achievements. The U.S. and its allies responded to these challenges by investing heavily in researching and developing principles, methods, processes, and tools for military defence systems, complemented by initiatives addressing industrial and other governmental systems. Landmark results included the codification of operations research and system engineering.

Two further sources of challenge began to emerge in the 1960s and accelerated in the 1970s through the 1990s: awareness of the criticality of the human element, and the growth of software functionality in engineered systems.

Concerning awareness of the human element, the response was a reorientation from traditional SE toward "soft" SE approaches. Traditional hardware-oriented SE featured sequential processes, pre-specified requirements, functional-hierarchy architectures, mathematics-based solutions, and single-step system development. A Soft Systems approach to SE is characterized by emergent requirements, concurrent definition of requirements and solutions, combinations of layered service-oriented and functional-hierarchy architectures, heuristics-based solutions, and evolutionary system development. Using software engineering, we can apply the principles of SE to the life cycle of computational systems (in which any hardware elements form the platform for software functionality) and of the embedded software elements within physical systems.

Evolution of Systems Engineering Challenges

Since 1990, the rapidly increasing scale, dynamism, and vulnerabilities in the systems being engineered have presented ever-greater challenges. The rapid evolution of communication, computer processing, human interface, mobile power storage and other technologies offers efficient interoperability of net-centric products and services, but brings new sources of system vulnerability and obsolescence as new solutions (clouds, social networks, search engines, geo location services, recommendation services, and electrical grid and industrial control systems) proliferate and compete with each other.

Similarly, assessing and integrating new technologies with increasing rates of change presents further SE challenges. This is happening in such areas as biotechnology, nanotechnology, and combinations of physical and biological entities, mobile networking, social network technology, cooperative autonomous agent technology, massively parallel data processing, cloud computing, and data mining technology. Ambitious projects to create smart services, smart hospitals, energy grids, and cities are under way. These promise to improve system capabilities and quality of life but carry risks of reliance on immature technologies or on combinations of technologies with incompatible objectives or assumptions. SE is increasingly needed but increasingly challenged in the quest to make future systems scalable, stable, adaptable, and humane.

It is generally recognized that there is no one-size-fits-all life cycle model that works best for these complex system challenges. Many systems engineering practices have evolved in response to this challenge, making use of lean, agile, iterative and evolutionary approaches to provide methods for simultaneously achieving high-effectiveness, high-assurance, resilient, adaptive, and life cycle affordable systems. The emergence of system of systems (SoS) approaches have also been introduced, in which independent system elements developed and deployed within their own life cycle are brought together to address mission and enterprise needs.

Creating flexible and tailored life cycles and developing solutions using combinations of engineered systems, each with its own life cycle focus, creates its own challenges of life cycle management and control. In response to this, enterprise systems engineering (ESE) approaches have been developed, which consider the enterprise itself as a system to be engineered. Thus, many of the ambitious smart system projects discussed above are being delivered as a program of managed life cycles synchronized against a top down understanding of enterprise needs. It is important that within these approaches we create the flexibility to allow for bottom-up solutions developed by combining open, interoperable system elements to emerge and be integrated into the evolving solutions.

More recently, emerging technologies such as artificial intelligence, machine learning, deep learning, mechatronics, cyberphysical systems, cybersecurity, Internet of Things (IoT), additive manufacturing, digital thread, Factory 4.0, etc. are challenging approaches to SE.

Many of the challenges above, and the SE response to them, increase the breadth and complexity of the systems information being considered. This increases the need for up to date, authoritative and shared models to *support life cycle decisions. This has led to the development and ongoing evolution of model-based systems engineering (MBSE) approaches.*

Future Challenges

Future systems will need to respond to an ever growing and diverse spectrum of societal needs in order to create value. Individual engineered system life cycles may still need to respond to an identified stakeholder need and customer time and cost constraint. However, they will also form part of a larger synchronized response to strategic enterprise goals and/or societal challenges. System life cycles will need to be aligned with global trends in industry, economy and society, which will, in turn, influence system needs and expectations.

Future systems will need to harness the ever-growing body of technology innovations while protecting against unintended consequences. Engineered system products and services need to become smarter, self-organized, sustainable, resource efficient, robust and safe in order to meet stakeholder demands.

These future challenges change the role of software and people in engineered systems. The Systems Engineering and Software Engineering knowledge area considers the increasing role of software in engineered systems and its impact on SE. In particular, it considers the increasing importance of cyber-physical systems in which technology , software and people play an equally important part in the engineered systems solutions. This requires a SE approach able to understand the impact of different types of technology , and especially the constraints and opportunities of software and human elements, in all aspects of the life cycle of an engineered system.

All of these challenges, and the SE responses to them, make it even more important that SE continues its transition to a model-based discipline.

2) System Engineering challenges in designing a Ignition systems in Liquid rocket engines

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Introduction

Design of complex systems like igniters often involves myriad integrated aspects and variety of parameters like mass flow rate, temperature and velocity of propagation. Adopting a system engineering approach helps streamline the design process, leading to greater efficiency and high quality igniters.

A system engineering approach is essential for an efficient design in a complex system like igniters. Typically, the ignition process of a liquid rocket engine involves non-linear interactions between multiple engine components with phenomena such as flow resistance, turbo pump operation, heat transfer, phase change, and combustion. Comprehension of conflicting requirements mentioned above and their integration are key elements lies the success of ignition system. This article highlights the challenges, interaction of different engineering disciplines, their understanding for designing suitable ignition systems for the Liquid Rocket Engines.

System Engineering Challenges

The design of complex systems like igniters can't be carried out without having clear understanding of all the participating rocket engine subsystems and the role played by each of them. Efficient design of the ignition system can be achieved by utilizing the systems engineering approach right from the concept stage. It focuses on the capturing the core challenges and requirements at very early stage during the development cycle, documenting each and every development process, carrying out the design in details considering all aspects, proceeding with the design phase, and validating the designing by closely monitoring the entire development process.

The designer needs to understand both the theoretical and practical aspects of the ignition process. All the system engineering process must be followed strictly, including requirement analysis, strategies of manufacturing *and meeting the requirements, the design synthesis and finally verification and validating the design process through a series of tests.*

A holistic approach must be implemented to mitigate risks all through the design and development phase of the ignition system. Designers should consistently monitor the technical performance without compromise on the quality, schedule, interfacing requirements and cost. Verification and validation are important processes to ensure that the design output meets the design requirements. Therefore, application of system engineering to complex structure like ignition system become essential to realise a system with high quality, while meeting the schedules and avoid cost escalation.

Ignitions Systems

Ignition is a critical step in the operation of a rocket engine. The ignition system has to deliver a specific mass flow rate at a specific temperature into a combustion chamber. Dependent on the local mixture ratios in the combustion chamber and the temperature of the hot igniter gases, ignition occurs.

Reliable ignition has to be guaranteed and the initiated turbulent diffusion flame has to stabilize without overpressure or blow out. Atomization is adjusting to the transient injection conditions and the flow field in the combustion chamber has to adapt continuously to the actual status of the flame as well.

System Development & Decomposition

The design process in complex systems like rocket igniters can't progress smoothly without having a clear knowledge of differing requirements of all participating subsystems as mentioned earlier. This can be achieved through the design iterations to sort out the parameters which are likely to cause hindrance. In addition, good clarity on the interfacing systems is very much required to accomplish the task.

The design needs in such complex systems are essentially identified as listed below:

- *Understanding the overall functional requirements of the ignition system.*
- *Generating the explicit system definition from the overall ignition system requirements.*
- *Identifying different subsystems and components that are to be realized for integrating the ignition system.*
- *Designing the fixtures and jigs required for the assembly and integration and testing of the ignition systems.*
- *Spelling out broader specifications for Assembly, Integration and testing requirements for each of the subsystems, so that their design tasks can be carried out independently.*

The design requirements of the ignition systems and subsystems have to meet not only the functional requirements, but also satisfy the defined constraints imposed by the overall propulsion system requirements.

Figure – 1 below illustrates a typical system engineering process to be followed meticulously in building complex systems like ignition systems. The left leg in the figure elaborates the design process, the right leg deals with the system integration along with the verification and validation process of the design. The bottom horizontal zone represents the entire manufacturing and realization process involved in the system.

The greatest challenge lies in building a common data base for the entire ignition system and updating the same periodically whenever change occurs in the design, assembly and integration, testing and manufacturing process, which can help avoid design errors. All the stockholders must utilize the common database to eliminate risk and errors during the different phases of design, assembly and integration, testing and manufacturing process.

The optimum design of an ignition systems involves various steps, including understanding both theoretical and practical aspects of the ignition process, which involves an initiation system, an energy release system and the hardware and other component that physically contain and provide for mounting them in or on the rocket engine. Defining proper interfaces between disciplines are important in order to arrive at robust design. The ignition systems are subjected to hostile environments like temperature, vibration and shock during flight. Predications of *changes in these environment parameters must be assessed carefully and suitable margins have to be built into the design to take care of such uncertainties.*

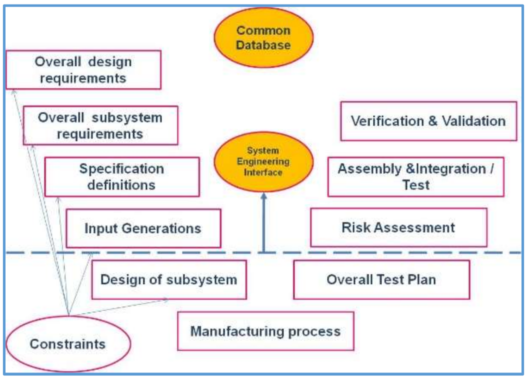

Fig1. Typical lifecycle process

In space missions, quality and cost are the two important factors that need serious consideration. Space systems aren't tolerant – even for a minor quality lapse and hence, the quality and reliability should be consistently watched during the design and development phases. During realization of the ignition system itself, the manufacturing and testability techniques have to be evolved parallelly.

Risk Assessment

One of the prime steps in system engineering is assessing the risk involved and its evaluation through a systematic failure simulation and analysis during the design phase itself. Strict configuration control of all the elements and subsystems is a major activity that enables full traceability during the entire lifecycle of the system realization from concept to operation.

A detailed tradeoff study is required between system identification, requirements, configuration and definition, which can eliminate the risk during the initial phase itself.

Risk assessment should be carried out in such a way that the kind of failures, their possibilities and their consequence shall be well understood. The analysis must clarify the risks as acceptable or otherwise, depending on the consequences. Such analysis results demand incorporation of the design improvements wherever necessary.

System Testing and validation

During the realization phase of the components, subsystems and systems, devising judicious test methodologies is crucial to their performance evaluation. A suitable matrix of tests must be generated to evaluate the performance of all subsystems in a progressive manner. Not only do they need to address performance evaluation, but also environmental test depending on the kind of environmental experienced by each of the subsystem (Thermal, vibration, shocks, acoustics) is essential.

A unified test bed to be evolved for assessing the performance, rather than different test bed with specified objectives for evaluating different aspects.

Furthermore, we need to carryout tests by integrating the flight hardware in a progressive manner to evaluate the performance of the ignition system in actual environment. This integrated test helps to establish the system robustness under all combinations of engine operating environment.

Conclusion

Designing complex systems are essentially multidisciplinary, and today almost all systems starting from simple toys to complex launch vehicles are highly multidisciplinary with serious interrelationships. Therefore, the realisation of such systems meeting the quality requirements, adhering to the projected schedule and staying within *the envisioned costs can't be done without the interference of system engineering. It also helps us to understand the complexity involved and minimizing risk, helping to achieve a great success rate.*

The entire process was explained by considering a complex system like an ignition system, where understanding the real requirement of igniting the rocket engine without any chance of failure is a challenging task.

3) The new wonder material - Borophene

Author: Miss. V. Chippy, Sci./ Engr 'SD', CAIST/ AIIS/ Automation & Instrumentations Systems, IPRC

For years, graphene was the wonder material that everyone was excited to work with. We can make bits of it from a pencil, yet it had all sorts of wonderful properties. The key, of course, is that it is a single layer of atoms. Now scientists have taken bits of boron to form borophene, and it looks to be even more exciting than graphene. The concept of borophene has been theorized back in the 1990s, but it was only in 2015 that scientists managed to synthesize it. This brave new material-based world is yet to be materialized. But is has triggered an interest in crystalline materials.

The reason for the excitement is the extraordinary range of applications that borophene can be used for. Boron atoms are arranged in a flat hexagonal structure such that a significant portion of boron atoms bind only with four or five other atoms and this result in vacancies in the structure. The vacancy patterns give borophene their unique properties. Borophene is found to be stronger than graphene and more flexible. The material is an excellent conductor of electricity and heat and also exhibits superconductivity. It is light and fairly reactive, which makes it a good choice for storing metal ions in batteries. "Borophene is a promising anode material for Li, Na, and Mg ion batteries due to high theoretical specific capacities, excellent electronic conductivity and outstanding ion transport properties", say Wang and co. Outstanding catalytic performances of borophene to catalyze the breakdown of molecular hydrogen into hydrogen ions, and water into hydrogen and oxygen ions could be used in a new era of water-based energy cycles. It shows a vast application prospect in gas sensor. It has been reported that borophene can be used as a sensor for ethanol, formaldehyde and hydrogen cyanide detection.

On the other side, the material is highly reactive and subject to oxidation. So not only the material is hard to create but also hard to handle, store and use as well. There are yet to find ways for synthesizing borophene in large quantities and needs to be protected since it is vulnerable to oxidation. Hence, there is work ahead. Borophene may just become the next wonder material to entrance the world.

4) Hydrogen based Vs battery-based transportation systems

Author: Mr. Pillai Mahesh Anil Kumar, Sci./ Engr 'SC', CSAID/ CSAIG/ Stage Assembly & Integration Entity, IPRC

This is time to shift towards zero emission transportation systems which is evident from the latest Intergovernmental Panel on Climate Change (IPCC) report. Although India still is leagues behind countries like USA, China and Germany in per-capita CO2 emissions (Figure 1) and greenhouse gas emissions (Figure 2). We need to look forward towards creating a sustainable eco-system of technologies by continuous research.

Global warming is real, and it is affecting the only home we know of. And one of the main contributors towards global warming is transportation systems and its breakdown of energy in transport sector (Figure 3). The alternatives are Electric Vehicles (EVs), both Fuel Cell EVs (FCEVs) and Battery EVs (BEVs).Battery Electric Vehicles (BEVs) are vehicles which only use batteries to drive the electric motor. These batteries are recharged or replaced at charging stations. Famous vehicle of this type – Tesla Model 3.

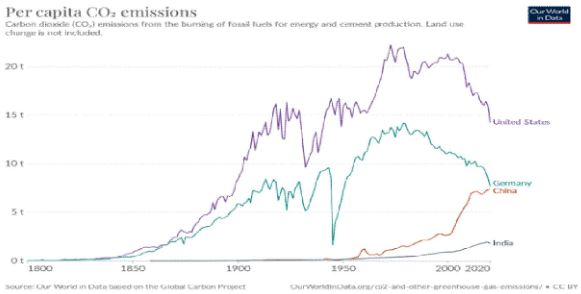

Figure 1: Indicative per-capita CO_2emissions history over time, courtesy the Global Carbon Project

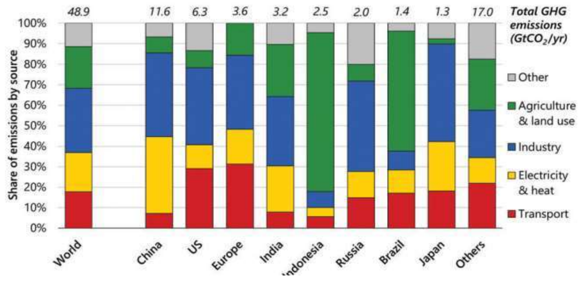

Figure 2: Global greenhouse gas emissions in 2014, broken down by sector, courtesy CAIT

Fuel Cell EVs (FCEVs)

Hydrogen is the most abundant element in the known universe, and it is readily available by electrolysis of water. It also has an impressive specific energy (40,000 Wh/kg). Furthermore, it can be produced in large quantities with essentially zero carbon emissions using renewable sources of energy (called Green Hydrogen). The Fuel Cell (FC) technology, even though in its infancy, is still more energy efficient than Internal Combustion Engines (ICE). It is smaller and lighter too, used in handheld devices and aerospace applications. Furthermore, fuel cells produce only water as a by-product, which is environmentally safe. FCEVs employ the best of both worlds; they employ an energy dense material to produce electricity in an efficient method. Further research into this technology will help bring the costs down, as countless promising research shows.

Battery EVs (BEVs)

Batteries have been used to power electronics for the major part of last 5 decades. It is an established, reliable and efficient power delivery system. We have made great progress in going from the Voltaic cell (1799) to wafer thin Li-ion cells (2020). Li-ion batteries have a specific energy of about 250 Wh/kg. During this journey, batteries have also become more sustainable in production methods, as well as usage of less corrosive and eco-friendlier chemicals. Research into this sector may very well bring down costs as well as increase the energy density. Exciting new research into super capacitors may well transform the BEV landscape by eliminating many of the present-day challenges as well as increasing the affordability. Graphene, the wonder material, may be used in the future to power our electronics.

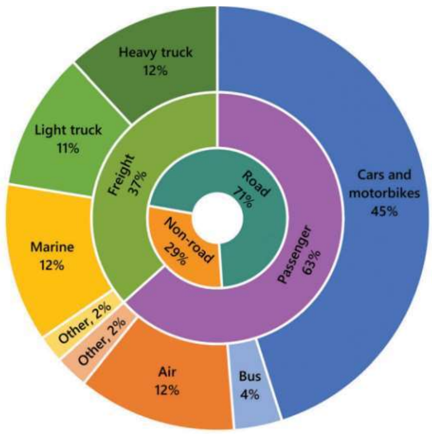

Figure 3: Breakdown of energy usage in the transport sector globally in 2015, courtesy Energy Information Administration, 2017.

FCEVs vs BEVs

Ease of Transition

BEVs are further ahead in the consumer market setup. Support systems, like fast charging stations and material delivery lines for manufacturing batteries, have already been set up and are ever increasing in scale of production. That being said, BEV charging stations are still far and few in between, and are yet to be supportive of all the various attachments and fast charging adaptors used by companies.

FCEVs on the other hand, have comparatively very less presence. There are currently no known products in the two-wheeler segment, and the four-wheeler market for FCEV has few niche products meant to showcase their potential, none of which fits the common man's use case. Also, hydrogen re-fuelling stations are rare and very poorly spread, with majority available in cities and developed countries. All this translates to very poor consumer adoption.

With the EV space being still in its infancy, the ease of transition is still a limiting factor. With various governments across the world committing to EV transportation, there is a rich demand which companies across the globe can tap into. In the future, it is highly probable that both BEVs and FCEVs will continue to become more and more accessible to the general public, with BEVs being further ahead in the curve.

Economic viability

There are BEV options already within the budget of the common man, especially in the two-wheeler market, thanks to government subsidies. Companies like Aether, Ola and others have units which are available at competitive pricing. Innovative designs, stylish look have already contributed to the trend, all of which helps promote the assimilation of the EV products into the market. In the four-wheeler segment, heavy-weights like Tata, Maruti Suzuki and others have already begun delivering their products, which cements the BEV place in the Indian market.

FCEV are still very new, and their products rare. However, Toyota, Yamaha and other automotive companies have already had proof-of-concept designs and showcased their prototypes at various Auto-Expos since 2018, shown in Figure . In developed countries like USA and Japan, there are consumer grade Mirai units plying in the streets of California and they been favourably reviewed. However, these are still vanity products, oftentimes being many times pricier than the petroleum based alternatives.

Figure 4: Toyota Mirai, showcased at Auto Expo, 2018

FCEV has the potential to revamp the civilian automobile industry, but it has been phenomenally late in delivering their work. As such, it seems probable that the first consumer grade EVs would mostly be BEVs. Later on, once the appropriate support systems are realised, it could possibly be adopted by consumers.

Usage

The most pertinent factor when it comes to EV adoption is ease of re-fuelling and range. At present, BEVs employ charging stations with proprietary adaptors. Some companies provide at home charging amenities (specially two-wheelers). BEV charging usually takes upwards of 30 minutes even for high end models. Also, the batteries *themselves are prone to failures, because the quality standards are still evolving. Range of BEVs is increasing by leaps and bounds, with each successive generation providing magnitude increase in range. Recent advances in battery swapping methodology may well be able to solve the charging bottleneck, at least for the two wheeler models. Cars and trucks usually require much larger batteries, oftentimes integrated into the structure of the vehicle, and it seems unlikely that these would be swapped.*

FCEVs on the other hand, require comparatively lesser re-fuelling time, and provide far longer ranges than a typical BEV. The inconvenience of proprietary specialised adaptors is present in this domain too. Added to this is the irregular distribution of re-fuelling stations, primarily because of deficiency in hydrogen transportation lines and systems. Further work in these domains may very well go a long way towards addressing these short-comings.

At present, BEVs seem more usable to the general public. However, the real mettle of FCEVs come in niche operating domains, such as long haul trucks and ships, which require long ranges, and where the batteries in EVs would be quite heavy.

Sustainability

EVs require electricity, which is sustainable only as long as the generation is done using renewable sources. Modern contribution to electricity production is largely skewed by region and economic conditions, as shown in Figure .

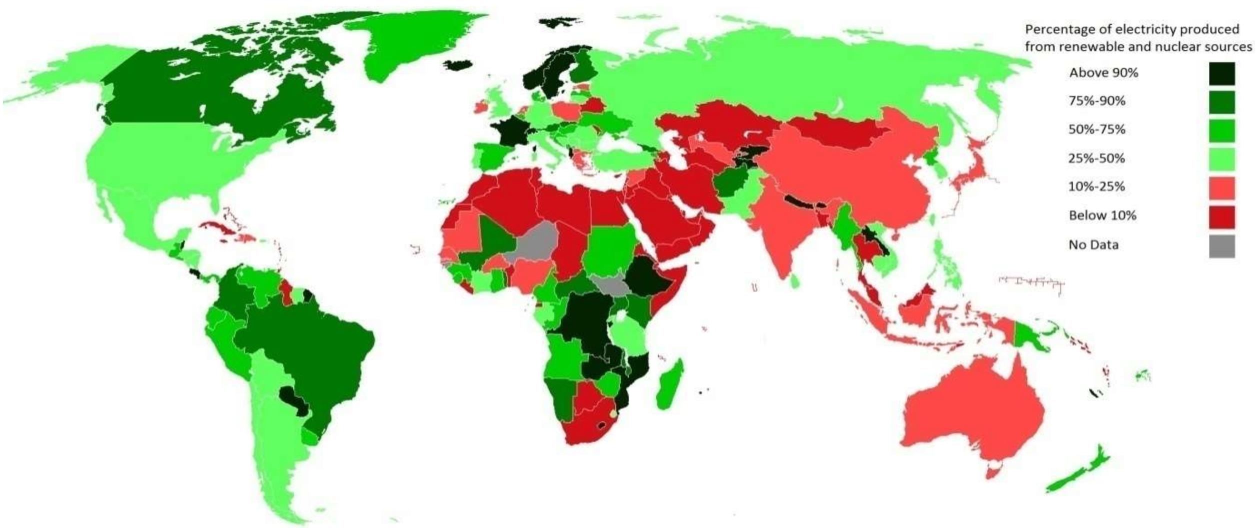

Figure 5: Percentage of electricity produced from renewable and nuclear sources, courtesy International Energy Agency (IEA), Electricity Information, 2017, www.iea.org.

Although EVs (production and usage) leads to a much smaller carbon footprint than petroleum based vehicles, the associated energy losses are much larger in FCEVs than BEVs. This is principally due to the various energy losses which occur inside the delivery process, i.e. from where the energy source is generated / produced to inside the electric motor.

Hence, from an energy conservation perspective, it makes more sense to prefer BEVs as compared to FCEVs. However, as the energy losses do not contribute significantly to ecological imbalance, there is no need to avoid FCEVs.

Conclusion

EVs are the future. Both the options discussed in the article have their own pros and cons. BEVs are more widespread and present lesser infrastructure based constraints, especially with the omnipresence of electrical energy. FCEVs are majorly lacking in these domains. Furthermore, BEVs have the ease of re-fuelling, with battery *swapping. FCEVs requiring sophisticated adaptors for re-fuelling and pressurised storage tanks, seem less consumer friendly. As the range for which the vehicle is designed increases, a BEV rapidly gets heavier and its efficiency decreases.*

All these points lead one to believe that BEVs would be the preferred mode of transportation for Indian civilian use cases, two-wheelers initially; with four wheelers being enticing once the charging infrastructure is in place. In the future, should emergent technologies deliver, it may well be the de-facto method of transport vehicles.

FCEVs could be used to power the transportation needs of the masses. The size and weight of the batteries required become untenable beyond a certain limit, both w.r.t mass and range. Buses, trucks and long range vehicles like ships can better benefit from the energy dense fuel that FCEV provides. Also, as most of these utilize specialised facilities for re-fuelling, oftentimes owned by entities having considerable funds, it seems prudent to assume that these markets would benefit from FCEV adoption.

From Editor's Desk:

Warm greetings to one and all.

We, ISSE-KK editorial board members thank President and Secretary of ISSE-KKC for given us a chance to part of this vibrant and enthusiastic team. The name of this e-magazine itself speaks of the vision of this tender ISSE-KK chapter. It is planned to release e-magazine on quarterly basis and will be uploaded in society's website and the same will be sent to members thorough e-mail. It is our commitment to provide platform for sharing knowledge among members from various field of interest pertaining to Science and Engineering. It is our earnest request to all members to make use of this opportunity to share their expertise and technologies.

We are grateful to the four authors who have agreed to share their technical ideas in this maiden e-magazine.

We acknowledge the timely support rendered by executive members especially Mr. K. Velmurugan, IPRC, continuous guidance & encouragement by ISSE- KKC, Secretary, Mrs. K. S. Deepa and valuable suggestion & tremendous motivation by ISSE- KKC, President, Mr. J. Asir Packiaraj.

It is our endeavor to continually improve the quality of this E-magazine. In this regard, feedback and valuable suggestions from readers are solicited.

feedback:visionkk@rediffmail.com

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