



Wrocław
University
of Science
and Technology



Brandenburgische
Technische Universität
Cottbus - Senftenberg

20th EEEIC

International Conference on Environment and Electrical Engineering – Student Edition



Wrocław - Ostrava - Cottbus

May 2021

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module at BTU: 12642

ISBN 978-3-940471-66-6

Presented by

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Publisher

Brandenburg University of Technology Cottbus - Senftenberg
Information, Communication and Media Center
University Library

Impressum

Brandenburgische Technische Universität
Cottbus-Senftenberg
IKMZ - Universitätsbibliothek
2021
ISBN 978-3-940471-66-6

[10.26127/BTUOpen-5657](https://nbn-resolving.org/urn:nbn:de:hbz:5:1-65567-p0011-9)

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Table of contents

DEVELOPMENT OF SOLAR TECHNOLOGY FOR A THIRD WORLD COUNTRY	1
ENERGY RESOURCES IN JAPAN	11
GERMANY'S ENERGY TRANSITION	16
E-MOBILITY: A COMPREHENSIVE STUDY AND ANALYSIS OF ELECTRIC VEHICLE CHARGING TECHNOLOGY	22
INTEGRATION OF ELECTRIC VEHICLES INTO POWER GRID: A STUDY ON VEHICLE-TO-GRID TECHNOLOGY	32
FUEL CELL HYBRID ELECTRIC VEHICLE TECHNOLOGY AND SIGNIFICANCE ON ENVIRONMENT	40
PELAMIS WAVE ENERGY CONVERTOR – TECHNIQUE FOR ENERGY GENERATION	48
ALTERNATIVE FUELS FOR VEHICLES AND LITHIUM-ION BATTERY TECHNOLOGIES FOR ELECTRIC VEHICLES: IMPACT ON ENVIRONMENT	56
ADVANCES AND INNOVATIONS IN THE FIELD OF PACKED BEDS USED FOR EXTRACTION AND ABSORPTION	65

Key words: Perovskite, Silicon, Solar cell, Efficiency, LCOE, Geography

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DEVELOPMENT OF SOLAR TECHNOLOGY FOR A THIRD WORLD COUNTRY

This paper seeks to provide an insight into the state of existing solar technology and seeks for an alternative that can be substituted for the same. This is done by comparing some of the performance parameters and the economic factors involved between various solar cell technologies. Following this, an attempt is made to integrate this technology within the existing power grid infrastructure of a developing nation. In order to select this nation, a wide set of guidelines are prescribed including a topographical analysis of the geography and various other geopolitical factors. Finally, a broad overview of the possible outcomes is concluded. Through this, it is hoped to achieve a benchmark that can be utilized by any organization, small or large to successfully substitute existing non renewables or obsolete renewables with a much more efficiently and economically designed energy structure based the existing landscape.

1. INTRODUCTION

Energy is possibly the most important tool today for the survival of humankind. From small appliances like our mobile phones to the large generators powering our manufacturing facilities, everything is run on energy. Today, this energy is supplied in bulk from conventional, non-renewable sources such as coal, natural gas and nuclear energy. However, when we look towards a cleaner and greener future for producing energy, one technology prominently comes to mind. Solar is fast overtaking other forms of renewables as the single most economical and widely distributable energy source and nations and economies all around the world are fast adapting to meet their energy demands from solar/ solar-hybrid sources. From its conception in the 1970s, solar has come a long way in terms of the reduction of manufacturing costs and

The per unit cost of electricity generated and the increase in the efficiency of energy production and the optimal usage of material for the cell production (Fig.1). Solar PV can broadly be classified into three generations:

Table 1 The different generations of Solar PV

1 st gen	2 nd gen	3 rd gen
Mono Silicon	Thin film Silicon	Dye Sensitized Solar Cell
Poly Silicon	GaAs	Organic PV
Amorphous Silicon	CdTe	Perovskite Solar Cell

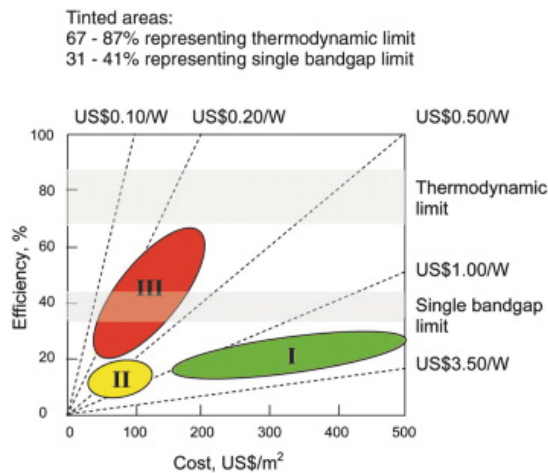


Fig.1. Efficiency and cost per unit electricity comparison of different solar cell generations [4]

Solar cell technology has been developed for years; however, the cost of electricity produced by the technology is still high. Most of the solar cell projects require the systematically support from governments such as feed-in tariffs (fits), renewable energy certificates (recs) [17], to name just a few. Therefore, there is an effort to reduce the levelized cost of electricity of solar cells to make them more affordable especially for the developing countries. Perovskite solar cell (PSC) is one of the promising technologies to compete with the existing commercialized silicon cells.

The advantages of PSCs in comparison to Silicon PV and other solar cells is analysed from 3 different perspectives namely: Performance comparison, economic comparison, and geographical consideration. Finally, an overall set of conclusions are provided (in the form of a set of guidelines) to determine if a developing world economy could make use of PSC technology to meet their energy demands.

2. PERFORMANCE COMPARISON

In this section, the performance between conventional solar and PSC is compared using 2 main parameters namely: Power Conversion Efficiency (PCE) and absorption coefficient. A further comparison is done between PSC based tandem and conventional solar cells. The enormous potential of PSCs is evident from the fact that the efficiency of these cells has risen from 3.8% to 25.5% within a decade (Fig.2).

A singularly unique characteristic of PSCs pertains to the fact that their chemical and material composition can be varied to absorb different wavelengths of the incoming light energy. This variability means that their bandgap, and indirectly their efficiency can be altered. This is especially handy when they are used in tandem with other types of solar cells in tandem, to broaden the wavelength of absorbed light and thus maximize the PCE.

An important improvement in cell architecture has been the substitution of Methylammonium (MA) with Formamidinium (FA) as the cation in the chemical structure

of all leading perovskite cells. This means that the PCE of the standalone variant is expected to soon cross over the barrier of 30%. Another structural advancement is the usage of solid-state mesoscopic structures as the transport material for the charge carriers instead of the earlier frequented, largely instable liquid electrolyte. This has improved both the efficiency and the usability of PSCs. (Table 2.) [16]

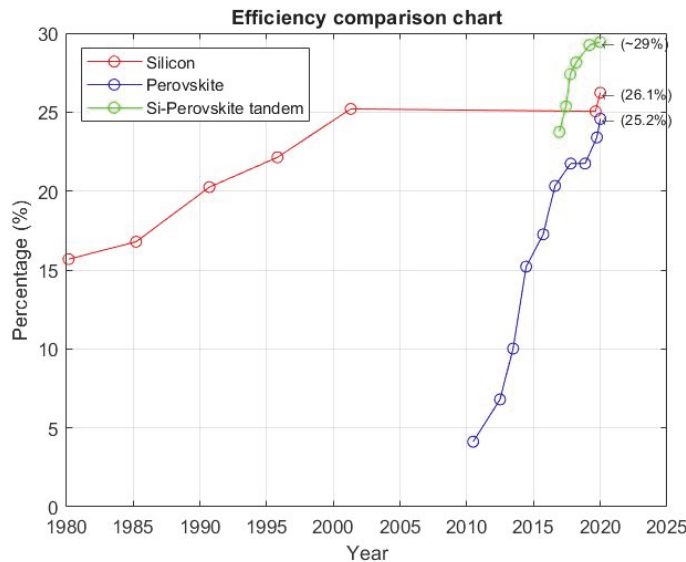


Fig.2. Performance efficiency comparison of PSCs, Si cells and Si-PSC tandem cells

Table 2: Some of the landmark efficiencies achieved with differing cell architecture.

PCE (%)	Cell Architecture	Year	Reference
3.8	Pt-FTO/Liq. Electrolyte/CH ₃ NH ₃ PbI ₃ /tio ₂	2009	Kojima et. Al. [2]
15	Au/spirometad/tio ₂ /CH ₃ NH ₃ PbI ₃ /Glass	2013	NREL, PV re-search cell [13]
20.2	Au/PTAA/Perovskite/(bl/m-tio ₂)/FTO	2015	Im et. Al. [7]
22.7	FTO/d-tio ₂ /mp-tio ₂ /NBH/P3HT/Au	2019	Jung et. Al. [8]

Another parameter considered here is the absorption coefficient (α) which is a measure of how easily the material can absorb photons. Higher the α , more the number of electrons can be excited into the conduction band. Visible light falls within the wavelength spectrum of 380-750 nm, which is not ideal for a Si based cell, whose absorptivity drops after 400 nm but perovskites with their tuneable bandgap have the potential to absorb a larger width of the visible light spectrum (Fig.3)

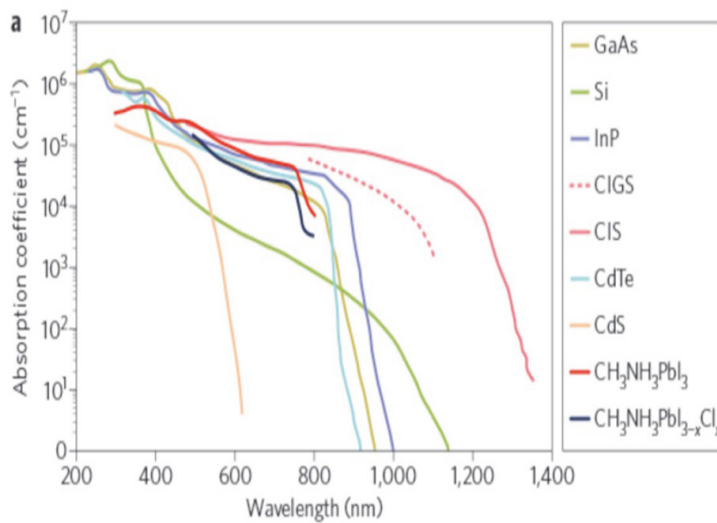


Fig.3. Comparison of absorption coefficient for various solar cell materials [5]

Commercially however, perovskites still face some challenges impeding its path towards large scale manufacturing and global use. Therefore, they are mainly used as a part of Si-Perovskite tandem cells with the currently best performing variant that was developed by Oxford PV having achieved a record PCE of 29.5%. Encapsulated 2-terminal Si/Organic -Inorganic metal halide perovskite solar (PSK) tandem cells with an efficiency of 23.6% are reported to be able to withstand up to temperatures of 85°C and 85% relative humidity. [15]

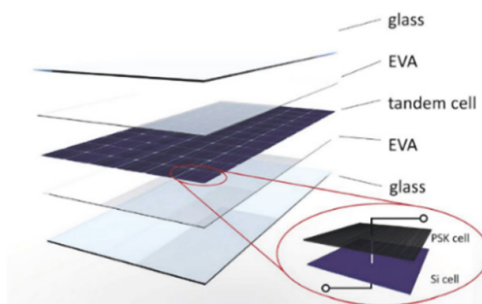


Fig.4. Cell architecture for a Si-PSC tandem cell [9]

Perovskites are considered as the most suitable upcoming technology for a new generation of PV modules but some of its drawbacks pertains to the usage of lead (Pb) in the synthesis of the chemical structure. In spite of all its merits, PSCs are still to demonstrate good device stability and extended lifetime when used as a standalone cell. Some of the problems, that include low-cost manufacturing of advanced fabrication of device architecture for the purposes of commercialization have been solved to an extent and the cells are able to withstand most structural-stress tests. [16]

3. ECONOMIC COMPARISON

The manufacturing cost is one of the most important cost when it comes to commercialization. The cost consists mainly of processing and material costs. Considering the production process of silicon solar cells, the today's silicon solar cells technology can be fabricated with high quality and achieve the power conversion efficiency (PCE) of up to 26.7% (theoretical maximum of 29.3%) [1,13]. To achieve the close theological efficiency, the high temperature process is required which is cost intensive and time consuming. On the other hand, PSEs is the solution processible that can be performed in a very low temperature due to its remarkable defect tolerant.

Currently, the PSCs technology has not been introduced into the industrial scale, consequently, leads to the challenge of real manufacturing cost estimation. However, there are various publication proposed numerous cases of manufacturing estimation which has been illustrated in the figure 5. The typical layers of perovskite solar cell consist of a glass substrate coated with a transparent conductive oxide, perovskite absorber between one for holes (HTL) and one for electrons (ETL). The basic and advance of those two researchers, Lisa et al and Chang et al, represent the level of complexity of the PSCs as well as the production method. The perovskite manufacturing cost of PSCs range from the lowest of 19.8 \$/m² [8] to as high as \$107/m² which is cheaper than 51.3 \$/m² [14] of silicon modules cost on average.

LEVELIZED COST OF ENERGY

The LCOE represents the unit cost of electricity over the lifetime of a certain generating technology, which is the measurement of competitiveness in the electricity market. There are various studies attempted to estimate the LCOE of perovskite technologies with the different methods as described in table 3. The LCOE cost ranges from 3.5 to as high as 5.5 us cents/kwh which is well below of that of fossil fuel technology (6.77 us cents/kwh, U.S. Energy Information Administration 2021).

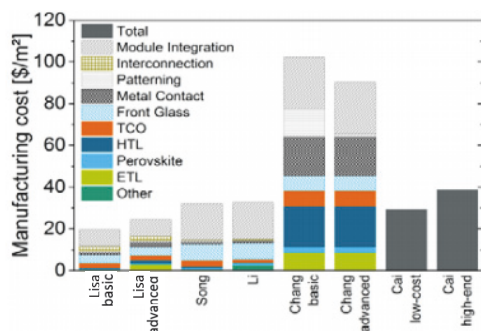


Fig.5. Comparison of manufacturing cost for perovskite single junction modules. [9]

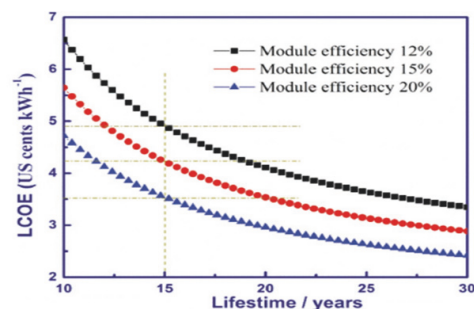


Fig.6. The relationship between LCOE and lifetime [10]

LCOE cost is dependence of module cost, efficiency, and lifetime. According to the study of Cai et al in figure 6, it is noticeable that the increase of lifetime and module efficiency reduces LCOE. The challenge of LCOE reduction is the lifetime of the PSCs. Since the material being used in PSCs are organic and inorganic substances, they are prone to be degraded and can be affected by light illumination, temperature, humidity, and interfacial reaction between functional layers. Eventually, these parameters lead to the critical impacts on the stability of PSCs.

Table 3: The estimation of levelized cost of electricity of various researchers for Perovskite PV cells.

LCOE [US cents/kwh]	Estimation Method	Conditions	References
3.5 – 4.9	Analysing two representative PSCs modules and calculated the corresponding LCOE	15 years lifetime	Cai et al. 2017
5.82		30 years lifetime	Song et al. 2017
9.0	Bottom-up “cost of ownership”	30 years lifetime, PCE of 30%	Chang et al. 2017
4.34 - 5.50	Bottom-up cost model	20 years lifetime	Z. Li et al. 2018
3.5 – 7.75 (utility)	Bottom-up model, PSC single junction and tandem cells.	25 years lifetime	L. Zafoschnig et al. 2020

4. GEOGRAPHICAL COMPARISON

By the increasing development of the solar cell and its output energy, a proper selection of the region of deployment plays a very crucial role in the solar energy management. As the region must meet specific criteria to fulfil the needs that have to be taken out of the cell itself, moreover in this section criteria and different aspects will be discussed to show how to select a specific country or region of deployment. Along with a small example using the mentioned criteria on a real time region of deployment.

The following figure demonstrates the most important criteria that can affect the decision of selecting a region or a country. As shown the criteria are divided into three groups of measurements. Environmental which represents the solar radiation in this area, air temperature and the height. Moreover, the soil feasibility or the ability of the land to carry the deployment of huge number of cells in one place. Social which means the impact on the social life of the region such as whether the deployment would offer new job opportunities in the place if the plant would affect the landscape of the region and if the country has already legal restrictions on such technologies. And last in the previous sections it was already mentioned the economic aspects of selection of different technologies and how they would affect the total power output of the plant.

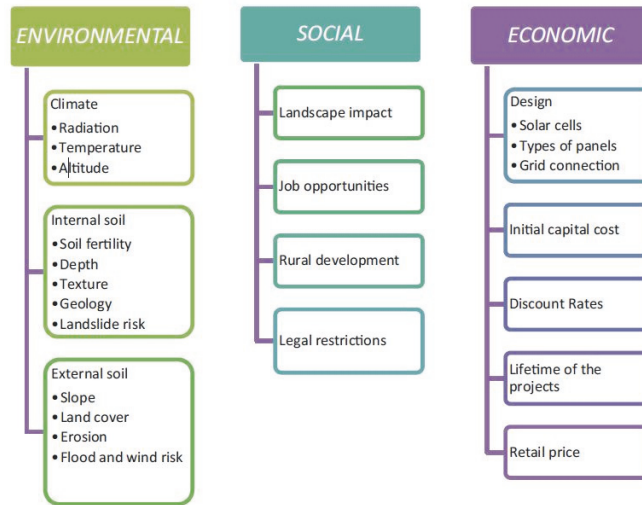


Fig.7. Representation of several major aspects during the selection of a region [10]

The process of selection involves exclusion which means elimination of suggested regions accordingly to the criteria.

Table 4: Example table taken out from [18] which suggests a method of exclusion during the selection of region of deployment.

Criteria	Definition	Selection
Areas excluded		
Environmental exclusion		
Risk areas	Areas with landslide risk, specific detachments or flood risk	Areas without risks
Geology	Geology: lithology is an important factor when excavation works have to be carried out for the installation of PV farms	Calcareous rock areas are eliminated
Legal and political exclusion		
Urban land use classification	Areas where it is impossible to implement solar PV power plants because it is prohibited by urban land use classification	Residential, industrial, protected, public, public domain urban soil and military areas are eliminated
Protected natural areas	Areas included in the Natura 2000 network, or areas which have a special natural interest	The Natura 2000 Network areas are eliminated
High-potential areas for solar farm development		
Location criteria		
Solar radiation	Electromagnetic radiation emitted by the sun	Areas with radiation below 4.2 h/day and more than 5.0 h/day are eliminated
Grid connection	Distance to the nearest electricity network connection, to the nearest power line or power transformer substation	Areas more than 1500 m away from a grid connection are eliminated
Accessibility	Accessibility of the solar farm site to the nearest road (minimum distance in meters)	Areas with no access to local or district roads are eliminated
External soil criteria		
Slope and orientation	Physiography/level curves	Areas with a gradient higher than 15%, or with north/west orientation, are eliminated
Land cover	Consultation of Information on the Spanish Land Cover and Use Information System (SIOSE 2015)	We identified the areas classified as suitable for agricultural and livestock production, rice cultivation, citrus and other fruit trees, olive and other woody crops, arable farming, with deciduous, coniferous, and evergreen species grassland, electric power production, as well as scrubland, idle land, and bare soil land. Areas with a cover below 30% are selected
Location criteria		
Temperature	Average temperatures measured by the weather station network of the Spanish Meteorological Service (AEMET)	Areas with temperatures below 10° C and above 20° C are eliminated
Altitude	Contour line map	Areas higher than 1800 m are eliminated

For the table 4, an example of exclusion of specific region, firstly risk areas such as area that might experience political issues or natural disasters must be excluded, secondly the topological aspects of specific region for example if the region suggested have valleys or mountains it is not recommend establishing solar power plant there. At the end location of region should be specific according to the technical requirements such as solar radiation, air temperature and grid connection. For the most influencing criteria it is the solar radiation factor that play a very important role in power generation as it is directly proportional to total power output. In the given figure an atlas map of the world and it is defined according to the solar radiation in each region or country.

By the given criteria and by following exclusion method it is suggested to select Yemen as the country of deployment. For the given reasons. According to atlas heat map Yemen has significantly has total solar radiation all over the year and the total number of sun hours per month. So, the total power can be harnessed is also significantly high enough to generate power that can contribute up to 30% of energy needed in Yemen. Second aspect is that Yemen does not have rivers for drinking water so huge amount of electricity used to desalinate water.

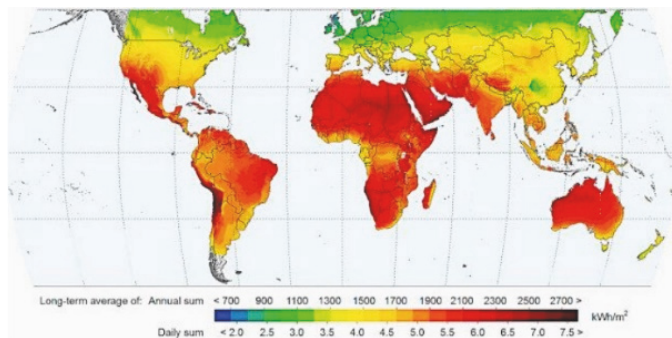


Fig.8. Atlas of world heat map [5]

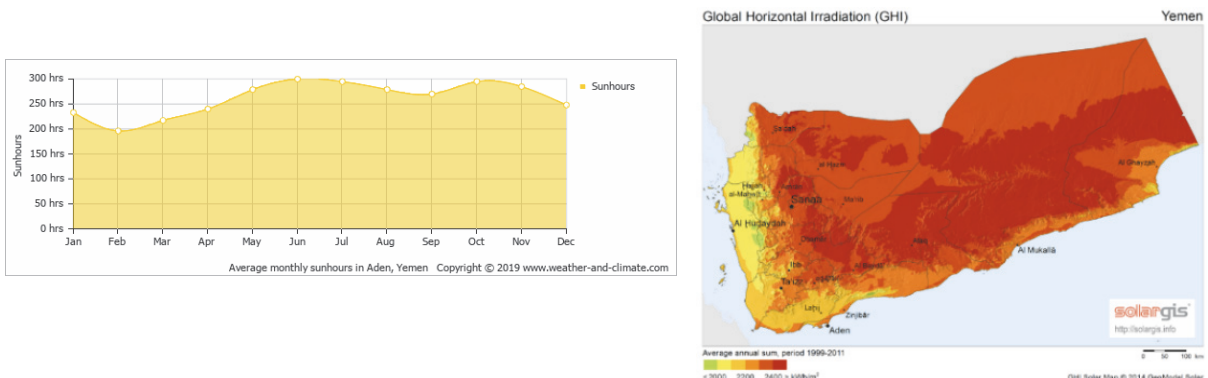


Fig.9. (a) Graphical representation of total sun Hours in Yemen during one full year (b) Atlas heat map of Yemen country [5]

Third aspect is the natural topological advantage of Yemen as a country which claim to have nearly flat ground which eases the deployment of power plant in this case from the geographical point of view.

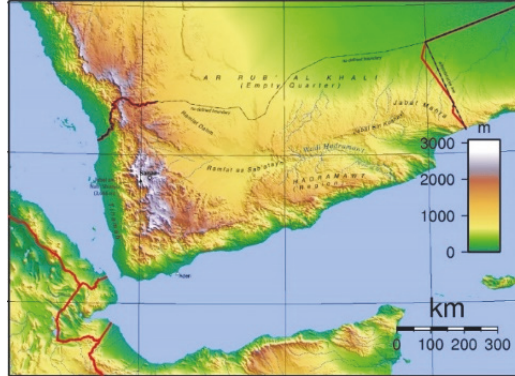


Fig.10. Topological Map of Yemen demonstrates the maximum and minimum heights in the entire country, Yellow parts represents an approximately height of 2000m [5]

For the previously mentioned aspects it is strongly recommend choosing Yemen as a country for deployment the solar power plant as it meets the criteria of selection and it would be a huge advantage to the country economic status due to the lack of water resources.

5. CONCLUSION

The bulk of the research being conducted today is in the domain of making the cell Pb-free (or in the least minimizing its content) and expanding the commercial manufacturing processes for usage in economies of scale. This huge potential of PSCs and its usage in tandem with Si is promoting many organizations and governments to invest heavily into this technology and it will play a larger role of generating cheaper electricity in the coming years. The perovskite PV cells technology is economically promising alternatives as the LCOE was estimated to be less than that of fossil fuels and silicon cells. Improvement of the lifetime and module efficiency is the key to significantly reduce LCOE, however, the recent development of PSCs still have much room to improve in terms of lifetime and efficiency to maintain its competitiveness. By mentioning the previous terms of assessing a geographical region, it can be also concluded that the major criteria based on the amount of sun hours per year and the topological aspects of the region/country, in this matter we can also select Yemen as the country of deployment for how it meets the criteria and assessments.

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Key words: Japan, Nuclear Energy, Traditional Energy, Coal and gas, Renewable energy, Future plans

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ENERGY RESOURCES IN JAPAN

Japan nowadays is considered one of the leading countries economically worldwide. This great country is facing problems regarding providing the energy that it needs and we here discuss which energy resources Japan uses the most and the effect of these resources on our environment plus the future plans for Japan to move from using traditional energy to renewable clean energy and the challenges that Japan is facing to achieve this move.

1. INTRODUCTION

The purpose of this paper is to provide an overview according to the statistics from previous recent years to show which energy resources that a big country like Japan depends the most and the challenges that Japan faces in order to provide these source, in addition to their effect on the environment. Then going through Japans situation towards the move to renewable energy resources instead of traditional ones and the challenges that Japan faces to achieve this important move.

2. JAPAN AND ENERGY USAGE GENERALLY

In 2019, Japan was the fifth oil consumer and the fourth largest importer of crude oil in the world. Japan is also the largest importer of liquefied natural gas in the world and the third largest importer of coal in the world.

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Before the 2011 earthquake, Japan was the world's third largest consumer of nuclear energy. Whereas, in 2010 the consumption of Japan from nuclear energy was 13%, while in 2019 it was only 3%.

After 2011, the use of nuclear energy was completely stopped and the share of oil, gas and coal increased at the expense of nuclear energy.

In recent years, plans have begun to increase the share of nuclear energy in order to reduce hydrocarbon fuel imports and enhance energy security in the country. Japan has the third highest electricity demand in Asia, yet the electricity demand growth rate is very small compared to the countries in the region (neighboring countries).

3. JAPANS SITUATION WITH TRADITIONAL ENERGY

According to the US Energy Information Agency, 950 terawatts of electricity were generated in 2019, as it was 4% less than in 2018 due to warm winter weather and low industrial production.

The share of fossil fuels is estimated at 70% of total electricity generation in 2019, which witnessed a significant increase from 2010, when the percentage was only 61%. Coal is also used mainly to generate electricity, as the share of coal before the Fukushima accident was about 26% and increased to 31% in 2019. Coal is used because it is cheaper than natural gas, yet Japan is trying to increase the use of natural gas in order to reduce CO₂ emissions.

As the use of natural gas to generate electricity increased from 27% in 2010 to 34% in 2019, in addition to that electricity generation by nuclear energy increased to 7% in 2019.

4. WHICH ENERGY SOURCES JAPAN DEPENDS THE MOST, THEIR PROBLEMS AND ENVIRONMENTAL EFFECT

Generally, energy is considered as a fundamental resource for human beings and to any nation lives on our planet. Japan in particular as a country has a big problem in providing such important energy resources such as oil, gas, and liquefied natural gas. And as a result Japan needs always a stable supply for this energy.

Looking back to 2017 we find that Japan had a low rate of energy self-sufficiency rater of 9.6 % in comparison with other OECD countries (Organization for Economic Co-operation and Development Countries). Although in 2014 was the lowest rate ever with around 6.4% of energy self-sufficiency rate, which confirms that Japan should face this big challenge of providing energy.

Japan depends the most on fossil fuels like oil, gas, LNG. In the previous year of Japan's Great Earthquake, fossil fuel was the main source of energy supply for Japan with around 81.2 %. Then the fossil fuel dependence became higher with around 87% in 2017 resulting from electricity problem which happened because of the shutdown of nuclear power plants.

Japan's source of fossil fuel is always imported from abroad, for example in 2018 the importing rate was as follows 99.7% of oil, 97% of LNG, and 99.3 % of coal.

When it comes to coal and LNG, we find that Japan depends always on Australia, Asia, Russia, and The Middle East which contributes with around 88% of the imported oil to Japan. And in the Middle East there are political instability problems and this represents a challenge for Japan and also for the energy importing market because the Middle East is considered as a big source of energy for the whole world. There was lately an accident, a ship full of cargo going to Japan was attacked neat the Strait of Hormuz, therefore the problem of navigational security is essential for Japan and to any other country that imports energy from the middle east region.

There is no doubt that the dependence on the traditional energy resources (oil, coal, LNG) contributes strongly in the increasing of the GHG amount of emissions, which plays an important role in harming our environment.

The amount of greenhouse gases has increased the most in 2013 with around 1.4 billion tons of emissions after the Great Japan Earthquake.

After that the amount of the GHG was reduced strongly, so we can find that the amount of 2017 emissions was less than in 2010, which is the year before the earthquake.

Looking at the shared amount of GHG emissions worldwide in 2018, we find that China had the biggest share with 26.6% followed by India with 6.7% in the 4th place, then Japan with a low share of 2.7% which reflects the Japanese efforts for saving our precious environment.

Japan's ability to be energy self-sufficient is really low and this is because it has poor resources, e.g. in gas and LNG. In 2015 The Energy Self-Sufficiency ratio was 7.4% which is low compared to the OECD countries. Japan is working hard now in the Research and Development of non-traditional resources like methane hydrate, oil and natural gas.

5. JAPANS SITUATION WITH RENEWABLE ENERGY

When thinking about the importance of renewable energy resources benefits, we find that it is vital, and one of these biggest benefits is the reduction of the GHG amount of emissions when producing electricity. In 2016 the renewable energy ratio that was used to produce electricity in Japan was 14.5% which is low in comparison with the leading countries, so increasing this amount is strongly required in the future.

Looking at the efforts that were performed towards the renewable energy. Countries were competing among themselves in the Renewable energy field that's why they invested a lot of millions in this field and its development . Because they believe that the future of energy lies in renewable energy especially after the growing demand for energy because of the globalization and Climate change.

Surprisingly Japan didn't pay great attention for investing in renewable energy although Japan is swing between third and fourth biggest economy in the world but it came in the sixth place after China, USA, Germany, rest of EU and Spain in the exploitation of renewable energy with 25,96 (GW) in 2010.

But after the catastrophic of March 11th in 2011 and disastrous consequences from power outage in almost all places in east Japan additionally great concern from radiation leak. The production rate of emission was growing in Japan year after year until it became 1,258 million of carbon in 2010.

Because of all these reasons Japan realized that it must pay more attention for investing in renewable energy and convert quickly to renewable energy. So that Japan has vision for 2050 and seek to replace almost more than two third from its need from energy to clean energy. This target will be achieved through reducing usage of traditional and nuclear energy from almost 90% in 2010 to almost 33% in 2050 and this ratio will come from 8% from nuclear reactors, 20% from gas power plant, 5% coal power plant

Besides this reduction, it will expand getting energy from renewable energy until almost 67% and it will come from 10% from wind turbine, 18% from solar panels, 14% from usage biomass, 10% from geothermal energy, 1% from pump storage hydro, 14% from hydrogen and Japan try to put a lot of effort to be able to precede other countries especially in getting energy from hydrogen.

During this converting, Japan need to raise its energy efficiency to be able to go on this planned way that's why it urges the Japanese to use the needed electricity only without any overuse, another side is that companies of electricity seek to follow strict laws to reduce consumption especially at the peak hours. This policy has been included increasing in electricity price at peak hours and running the factories during night. This policy didn't stop only at this point but also, they turned off light in 5,2 million vending machine and almost 17000 game machines on streets and only this rationalization process of these machines lead to stop running two nuclear reactors and by this way will speed up the process of converting to renewable energy.

Although Japan has great vision for future but it has a lot of challenges against achieving this vision firstly Japan has to reduce consuming electricity 50% in 2050 comparing to 2010, secondly converting to renewable energy is so expensive especially building new wind turbines and hydrogen energy, thirdly Japan is located on the storm and earthquakes belt and therefore definitely this will affect the wind energy and solar energy so that Japan pay more attention for hydrogen energy. Additionally, a lot of companies there don't trust in quickly converting to renewable energy and providing the market with enough energy because of these problems and nature in Japan but since 2010 Japan went step by step to its target and all indicators proves that in 2020.

6. CONCLUSION

In this paper we discussed Which energy resources Japan depends the most which were mostly traditional energy sources and how japan provide these sources from abroad eventhough the existence of challenges, and their effect on the environment. then we dicussed the self-efficiency ability of japan to fullfil its needs from the resources and how it can move to renewable energy sources instead of traditional ones. Then we showed japans Future plans for the usage of renewable clean energy and through that we clarified how the situation of Japan was from Renewable energy before 2010 then the Growth that happened in renewable Energy Capacity from 2005 to 2010. After that we showed the vision of japan for renewable energy usage until 2050 and which renewable sources will be included in this great vision. then we discussed the Challenges that japan will face when seeking to achieve this Plan until 2050 and how it can affect the Japanese economy . Finally, we show how this Plan was going from 2010 till 2020 and depending on that performance and results we believe if japan continue the same efforts till 2050, it can achieve this plan.

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Key words: energy transformation, expanding renewables, greenhouse gas reductions, energy policy.

Mayankkumar VALAND

GERMANY'S ENERGY TRANSITION

Germany's energy transformation is greatly known as the "Energiewende", is the country's planned transformation to a nuclear free with low-carbon economy. There are plenty of reasons behind this and major goals behind this is decarbonization by switching to the renewable energy resources and decrease the energy demand by being more energy efficient. Thereby to have an increase in energy security. This transition uplifts green innovations, produces more jobs, and Germany is also as a green technology's exporter. Germany produces half of the solar equipment of world. Germany is an innovator of green technology and its economy is an export-based economy, with a aim of exporting over 80 percent solar PV products by the year of 2020. Germany rejects nuclear power because of the risk of nuclear disaster like Fukushima and Chernobyl. In addition to this, nuclear power does not have the potential to play any major role in nearer future world energy supply. Moreover, another reason of energy transition is enhancing local ownership of renewables which provides superior economic payback to investing communities. In the longer run, energy efficiency and renewable both make energy cheaper for everyone.

1. INTRODUCTION

The term "Energy Transformation" means an alternative, clean, affordable, and sustainable way to generate and use energy. This means abandoning traditional power and heat generation, primarily through coal and nuclear power. And a goal towards renewable energy and energy efficiency. In the landmark Paris Climate Agreement, countries around the world committed to cutting greenhouse gas emissions to get climate change under control. Important policy document outlining the Energy Transformation was published by German government in September 2010. Following the March 2011 Fukushima nuclear disaster, Germany is decommissioning 23 of its Nuclear Power Plant and plans to dismantle all 7 of its running Nuclear Power Plants at the end of 2022. Additionally, the government has some targets till 2050, which focuses mainly on using Renewable Energy as our primary source of energy.

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2. TARGETS

Germany, like the European Union, targets to become a complete greenhouse gas neutral till 2050. Germany has set the primary objective of cut the emissions by at least 55 percent by 2030 in comparison to 1990 levels. The Germany's first climate law, which passed in 2019, defines yearly reduction targets for individual sectors like industry and transport until the year of 2030. These are directed in line with the European greenhouse and gas emission declination plans. Greater than 40 percent of the power utilization was covered by renewables in 2019 in Germany, overtaking the 2020 target of 35 percent one year ahead of the time. The government has the goal now at 65 percent by 2030, as is directed in its Climate Action Program 2030. Their share in country' final energy consumption, however, remains at lower level with 17.5 percent - although very near to the 2020 target of 18 percent. By 2030, the government is aiming for a share of 30 percent. [4]

Germany's renewable energy targets and status 2019

Data: BMWi, Second Progress Report on the Energy Transition (2019) / BMWi, AGEE-Stat (2020).



	Status		Targets			
	2018	2019	2020	2030	2040	2050
Share of renewable energies						
Share in gross final energy consumption	16.5 %	17.5 %	18 %	30 %	45 %	60 %
Share in gross power consumption	37.8 %	42.1 %	min 35 %	65 %*	65 %	min 80 %
Share in heat consumption	14.3 %	14.5 %	14 %			
Share in transport sector	5.6 %	5.6 %	10 % (EU goal)			

*Target from Climate Action Programme 2030

Fig. 1. Germany's Renewable energy targets [4]

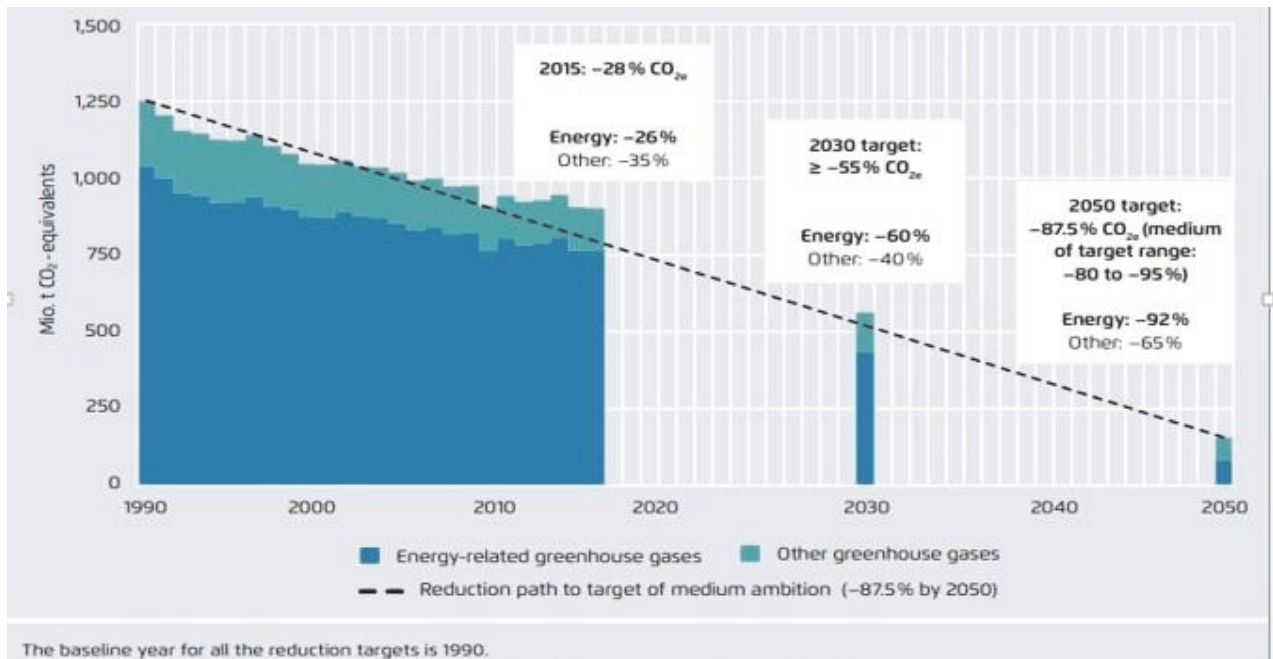


Fig. 2. Germany’s GHG targets by 2050 [1]

Germany's 2030 sector targets for greenhouse gas emission reduction and 2019 status

Data: UBA (2020) / Climate Action Law.



Sector	2019 status (cut from 1990 levels)	2030 target (cut from 1990 levels)
Energy	45.5 %	62.5 %
Buildings	41.9 %	66.7 %
Transport	0.6 %	42.1 %
Industry	33.8 %	50.7 %
Agriculture	24.4 %	35.6 %
Other	76.3 %	86.8 %
Total	35.7 %	56.6 %

Note: Without emissions from land use, land use change and forestry (LULUCF), 2019 data preliminary.

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Fig. 3. Germany’s GHG targets by sector [4]

3. AGORAS ENERGIEWENDE’S RECOMMENDATIONS

For Environmental protection, reduction of greenhouse gas emissions in the energy sectors by 60% compared to 1990 levels by 2030. Emissions must total no more than 166 million metric tons in the power sector, 175 million metric tons in the heating sector and 98 million metric tons in the transport sector of Germany [1]. Energy efficiency is the main part for success in the power, heating, and transport sectors in Germany. Achieving Germany’s climate targets without massive investment in green retrofitting, in more efficient power use and in transport system efficiency would not only be more costly; it would run up against the limits of public acceptance in view of the additional efforts needed in renewables expansion and coal diminution [1]. Between 2015 and 2030, Germany must cut final energy usage by around 22% and primary energy consumption by 29% (because of conversion waste). The expansion of renewables is the 2nd main pillar of the energy transition of Germany. By 2030, the share of renewables in Germany’s total primary energy dissipation needs to increase to around 31%, somewhat more than double what it is today. The third strategy is to focus on decreasing the most carbon-intense energy source in each of the energy sectors, as their diminution does the most to cut CO₂ per kilowatt hour. The use of coal and oil in 2030 will be halved compared to 2015 level [1]. The cleanest burning fossil fuel is natural gas; as such, it will see only a slight reduction by 2030.

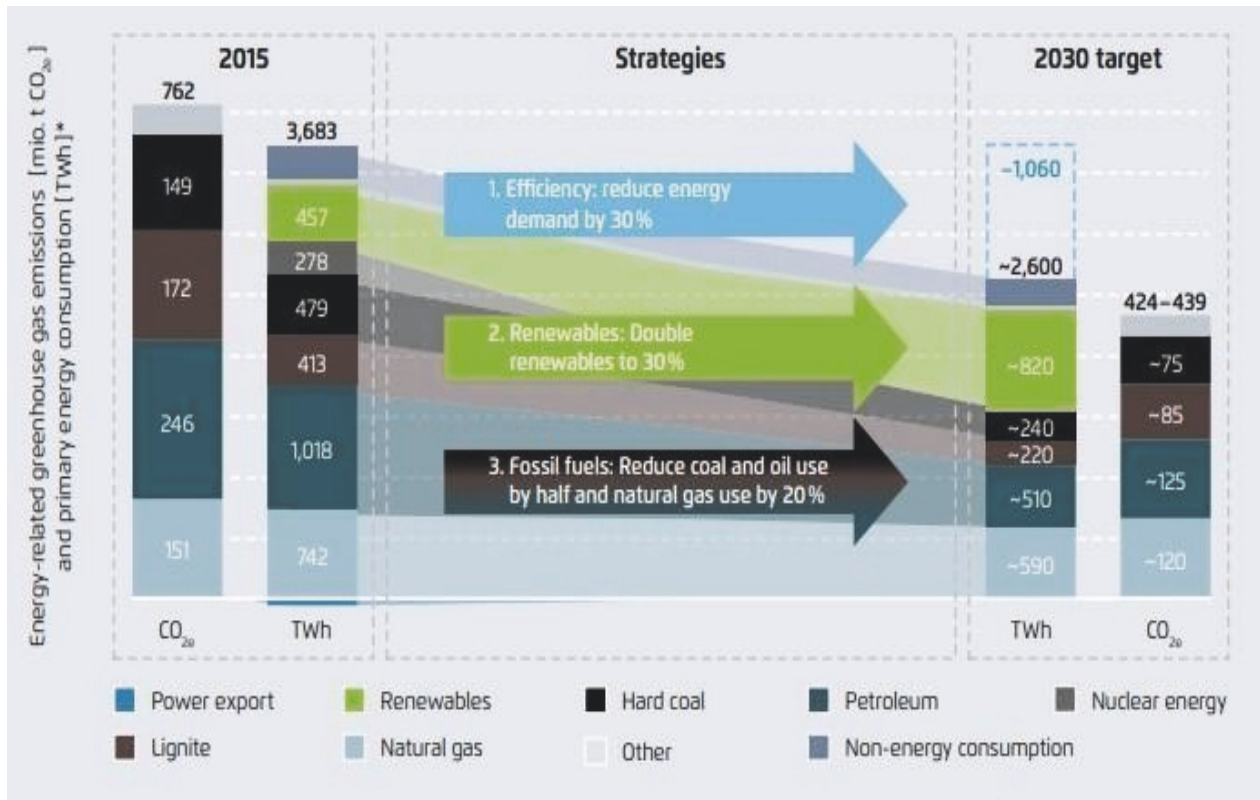


Fig. 3. Strategies for a Cost-Efficient Energy Transition by 2030 [4]

PRIORITY ACTION AREAS FOR A SUCCESSFUL ENERGY TRANSITION

The Priority action areas of fortunate energy transition can be summarized in seven points:

Table 1. Action areas of successful energy transition [2]

1	Develop renewable energies more quickly.
2	Secure supply: make consumption very flexible and provide dispatchable power plants.
3	Expand market and technologies for renewable synthetic energy carriers.
4	Shift to a new technology mix in the transport sector.
5	Enhance the extent and speed of energy refurbishment for buildings.
6	Avoid industrial emissions by efficiency, renewable energy sources and new processes.
7	Take an integrated approach to managing the energy transition to enable investment.

4. REDEFINING THE POWER, HEAT AND TRANSPORT SECTOR

Transforming the electric power sector: Nowadays, coal continues to cover 40 % of German electric power consumption, which should be replaced by mostly wind and solar technology by 2030. Between 2020 and 2030, on- and offshore wind farms and ground-mounted PV systems will produce electricity at under 5 cents per kilowatt hour. Roof-top PV will be common standard not only for single-family homes but for any building with a suitable roof [1].

Transforming the heating sector: By 2030, low-emission heating systems such as gas fired boilers or heat pumps must be mostly replaced by oil-fired boilers. District heating networks should draw their heat from a variety of sources: gas-fired CHP plants, solar thermal and geothermal energy, biomass, large-scale heat pumps and waste heat. Like this, Coal use for district heating and industrial process heat will be cut in half.

Transforming the transport sector: With 166 million tons of CO₂ emissions in 2016, transport is the only sector to release more carbon today than it did in 1990 [1]. The transport sector is undergoing a rapid transformation, which is called Verkehrswende, because of which more bicycles can be seen on road and people preferring Mobile Carshares and public transport. Electric cars and new mobility options should become more available, so that it makes cities quieter and cleaner, reducing noise along with other forms of pollution.

5. CONCLUSION

Germany sees itself as a pioneer in energy transition and climate protection around the world. Germany has already completed the first phase of the energy transition. The second phase of the energy transition of Germany, which extends through 2030, will be both easier and harder than the first phase (2000 to 2015) [1]. Agora's Energiewende has provided such a compass with its specific target strategies in environmental sustainability, economic competitiveness, and security of supply for 2030: reduce energy-related emissions by 60% down to 1990 levels; ensure energy costs remain below 10% of spending in the industrial sector and in private households; keep power outages to under 20 minutes per customer per year; and decrease the share of primary energy from imports to below 60% [1]. To ensure that its benefits for the German economy outweighs its costs, the energy transition should focus on efficient technology, wind and solar power expansion and the increased electrification of the heating and transport sectors through 2030 [4].

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Key words:
Electric Vehicle (EV), Charging Topology, off-board on-board charger, AC/DC/DC Converter

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E-MOBILITY: A COMPREHENSIVE STUDY AND ANALYSIS OF ELECTRIC VEHICLE CHARGING TECHNOLOGY

Electric mobility becomes trending issue than ever in transportation sector. The essential part of electric mobility is the use of electric vehicles. Different types of electric vehicle (EV) charging technologies are described in literature and implemented in practical applications. EV Chargers are classified based on their power levels and power flow direction. Referring to power ratings, EV chargers can be divided into Level 1, Level 2 and Level 3. Level 1 and Level 2 are normally compatible with on-board chargers while Level 3 is used for an offboard charger. Uni-directional/bidirectional power flow can be obtained at all power levels. However, bidirectional power flow is usually designed for Level 3 chargers as it can provide the huge benefit of transferring power back to grid when needed. This paper presents an overview of the existing EV charging technologies in terms of converter topologies, power levels, power flow directions and charging control strategies.

1. INTRODUCTION

The transport sector is the main responsible of the air pollution as it produces almost a quarter of all the greenhouse gas (GHG) emissions. There has been a decrease in the emissions since 2007, but they are still remaining higher than in 1990. Road transport, in particular, was considered responsible for more than 70% of GHG emissions from the transport sector in 2014. In the last decade, EVs have become in some way widespread, principally because of their negligible flue gas emissions and lesser reliance on oil [1]. It is estimated that by 2022, EVs will be over 35 million in the World.

EVs have been enhanced significantly to allow for a long driving range using novel battery technologies and fast charging stations. The high penetration of EVs at the grid point of common coupling (PCC) brings feasible solutions for utilizing EV batteries to stabilize the grid such as active/reactive power control, PCC voltage and frequency control, or mitigation of the output fluctuation of renewable energy sources [2], [3]. However, high EV penetration has not been achieved because of several critical barriers such as the high cost of batteries, limited charging/discharging cycles, and the shortage of public charging stations with fast charging facilities [4]. Based on the power ratings, the

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EV chargers can be divided into Level 1, Level 2 and Level 3 and the functionality of each of the Level is illustrated in Table 1.

EV battery chargers can be integrated in an EV as an onboard charger or separated as an off-board charger. The power flows between EV batteries and the grid can be unidirectional or bidirectional. The unidirectional power flow is implemented in all recent commercial on-board chargers because of the simplicity, and reliability in their topologies and control. Bidirectional chargers can be controlled to inject the EV battery power into the grid. This can help to stabilize the grid at peak demand [5], [6], [7].

The aim and the prime concern of this research study is to present the current status and implementation of EV battery charging technologies, power levels and charging infrastructure of these emerging technologies based on different scenarios.

Table 5. Charging Power Levels [8]

Power Level	Charger Location	Typical Use	Expected Power Level	Charging Time
Level 1 120 Vac (US) 230 Vac (EU)	On-board 1-phase	Charging at home or office	1.4kW (12A) 1.9kW (20A)	4-11 hours 11-36 hours
Level 2 240 Vac (US) 400 Vac (EU)	On-board 1 or 3-phase	Charging at public or private outlets	4kW (17A) 8kW (32A) 19.2kW (80A)	1-4 hours 2-6 hours 2-3 hours
Level 3 (208-600 Vac or Vdc)	Off-board 3-phase	Commercial, Analogous to a filling station	50kW 100kW	0.4-1 hour 0.2-0.5 hour

2. EV BATTERY CHARGER TOPOLOGIES

Battery chargers play a vital role in the development of e-mobility. EV battery chargers are designed based on fundamental DC of AC power converters which must have a high-power density, high efficiency. DC/DC converters are typically Buck/Boost or switch-mode converters, AC/DC converters are based on uncontrolled or controlled rectifiers. DC/AC converters are usually based on H-bridge inverters for single phase or three phase system. The charging/ discharging algorithms are implemented digitally using high performance processor or a field-programmable gate array (FPGA). Fig. 1 shows the general configuration of an EV charging system.

EV batteries can be either charged by an on-board charger (Level 1, 2) or by an off-board charger (Level 3). As can be seen in Fig. 1, all on/off-board chargers contain AC/DC converters and DC/DC converters. However, the topologies and the power rating of the converters in of each type of the chargers are totally different. Onboard battery chargers (OBC) are limited by size, weight and volume for this reason they are usually

compatible with level 1 and level 2 chargers. They usually have unidirectional power transfer capability; however in some cases a bidirectional power transfer can be achieved.

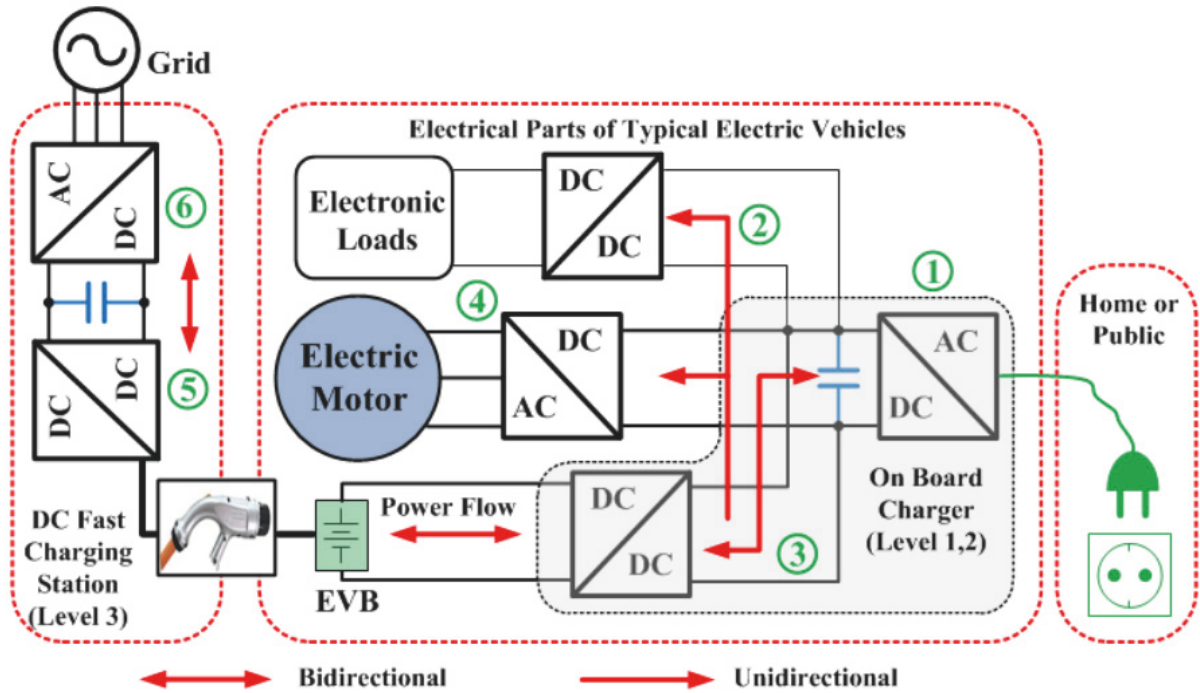


Fig. 1. Typical configuration of an EV charging system [9]

ON-BORAD CHARGER

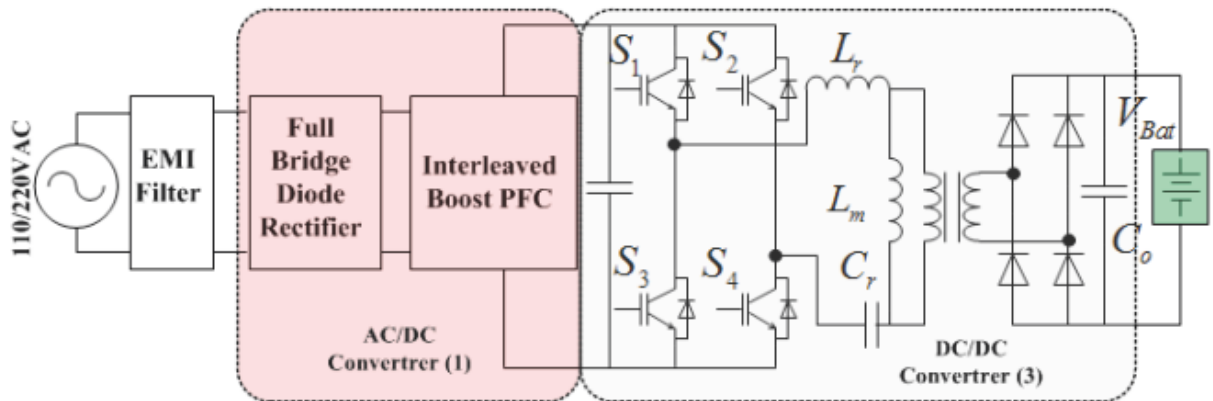


Fig. 2. A typical topology of an on-board charger with unidirectional power flow [10]

Onboard chargers are typically composed by two stages: a front-end AC–DC stage and a back-end DC-DC stage. The front-end rectifier usually contains a boost power factor correction (PFC) converter to achieve high power factor and low harmonic

distortion. The rectifier stage can be performed by a half-bridge, full-bridge or multi-level diode bridge. Half-bridge rectifier is less expensive since it contains less number of diodes/switches, full-bridge rectifier is more complex but the components are subjected to lower stresses. If instead higher power ratings should be achieved a good choice for the ac–dc converter is a multilevel configuration. Fig. 2 [10] shows a unidirectional on-board EV battery charger for Level 1 and Level 2 in which the AC/DC converter consists of an H-bridge diode rectifier and an interleaved DC/DC Boost converter.

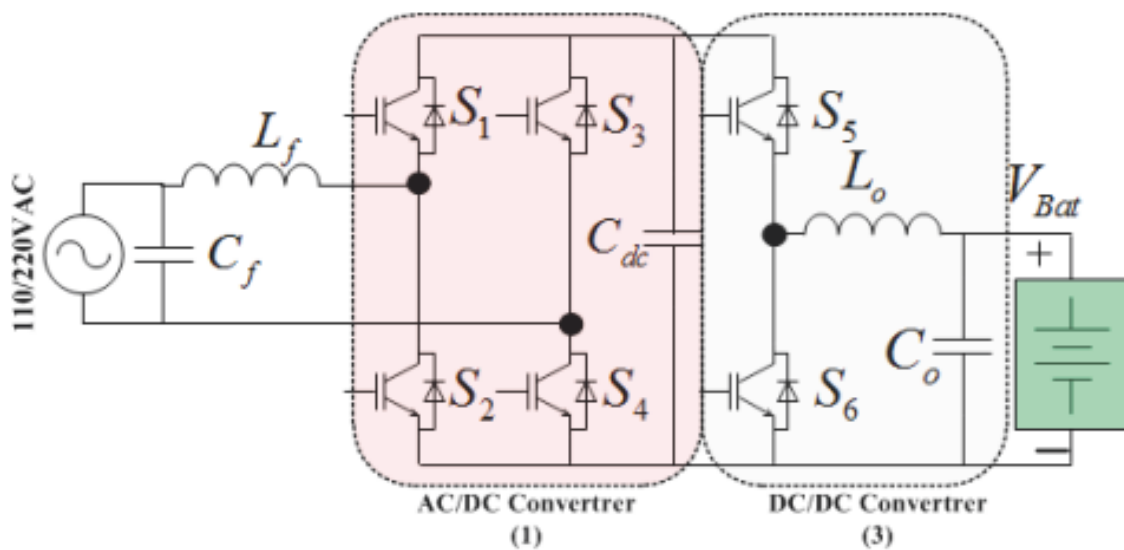


Fig. 3. A typical topology of an on-board charger with bidirectional power flow [13], [14]

This converter is controlled to attain a high power factor correction (PFC). The DC/DC converter is an H-bridge LLC-resonant converter which has higher efficiency as it can operate at wide load ranges with zero voltage switching [11]. It can be observed from Fig. 2 that different charger topologies can be proposed by replacing the components of AC/DC converter and DC/DC converter to improve the efficiency of the LLC stage. For instance, the authors in [12] use a SEPIC PFC to replace the interleaved boost PFC in the AC/DC converter to improve the efficiency of the LLC stage. A bi-directional on-board level 1 and level 2 charger topologies are proposed in [13], [14] shown in Fig. 3 where an H-bridge boost converter is used as a AC/DC converter and a bi-directional Buck/Boost converter for a DC/DC converter. This method not only control the EV battery charging current, but also produce reactive power to inject to the grid in order to support grid ancillary services.

The onboard charger should be installed in the vehicle and designed for the slow charging rate, that is, it takes longer time to charge relatively. Due to limitation in available space in vehicle and payload, the onboard charger for BEVs/PHEVs should be light

and compact in design. The advantage of onboard charger is that the battery can be charged at any place where there is electric outlet is available.

OFF-BOARD CHARGER

A level 3 off-board fast charging topology are presented in [2], as shown in Fig. 4. This topology uses a three phase AC/DC boost rectifier for the PFC charging operation and reactive power operation. However, the topology is only suitable if the DC voltage of EV battery V_{bat} is higher than V_{dc} . This converter can be implemented using a single or interleaved bidirectional Buck/Boost converter.

Multilevel converters as shown in Fig. 5 (a) can be the best candidate topology for Level 3 EV chargers as it can achieve a high-power density while reducing the stress on the power switching devices. These converters provide a good power quality at the Point of Common Coupling (PCC) with less harmonic currents. DC/DC converters with a three-level output voltage have also been studied in as can be seen in Fig. 5 (b). This converter has a high power density, and it is currently the best candidate for DC fast chargers.

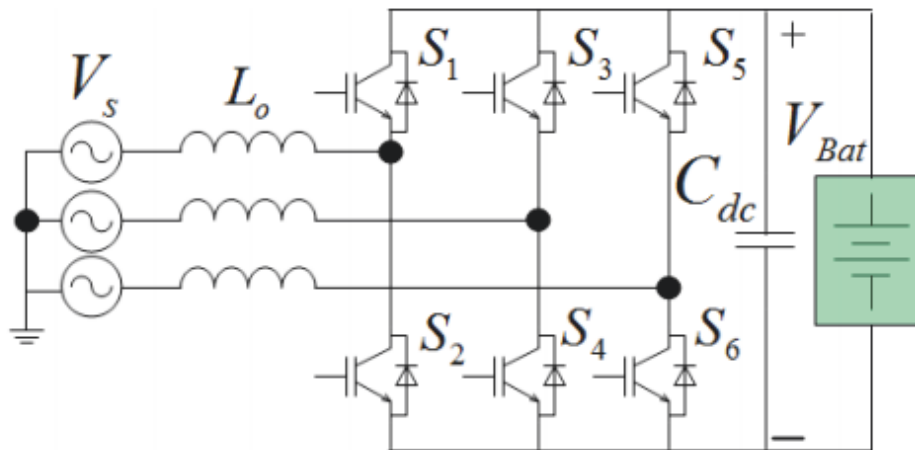


Fig. 4. Level 3 bi-directional off-board charger [2]

An off-board battery charger is less constrained by size and weight and keeps redundancy in power electronic converters, which adds flexibility in the system. The onboard and off-board charger are usually implemented either with unidirectional or bidirectional power flow. Initially, the unidirectional charging should be the first step because it reduces power electronic component requirement, simplifies interconnection issues and control complexity, and reduces battery degradation. These chargers typically use a diode bridge rectifier in conjunction with a power factor correction (PFC) and dc-dc converters.

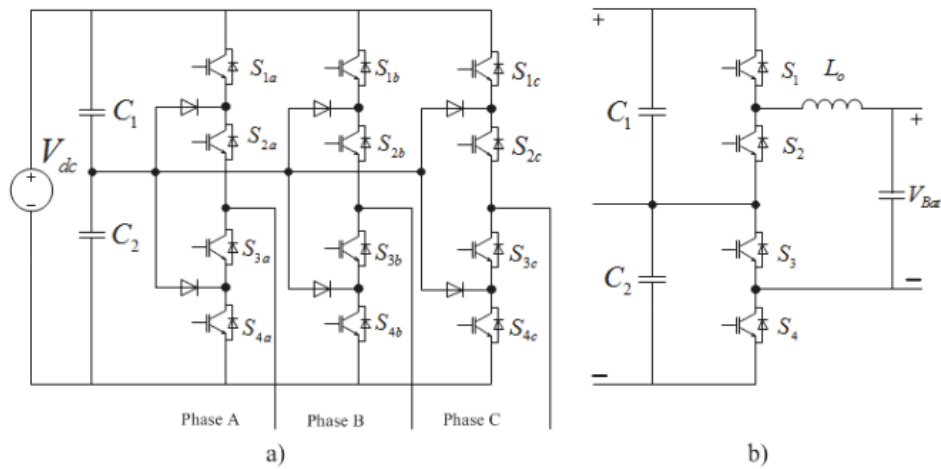


Fig. 5. a) Three-level diode clamped converter and b) Three-level dc-dc converter [15], [16]

3. CHARGING STRATEGIES

It is well-known that a large-scale of EV penetration can have severe impacts on the distribution grid such as the overheat of distribution transformers, voltage fluctuations, harmonic distortions etc. To deal with these issues, in the long term there additional upgrade for the grid infrastructure will be required. For the short term, controlled charging schemes should be applied. There are two charging strategies: uncoordinated strategy and coordinated strategy.

Uncoordinated charging means that EV batteries either start charging immediately when plugged in or start after a user adjustable fixed delay and continue charging until they are fully charged or disconnected. This charging system is most likely at Level 1. Uncoordinated charging operations tend to increase the load at peak hours and can cause local distribution grid problems such as extra power losses and voltage deviations that affect power quality. They may lead to overloads in distribution transformers and cables, increased power losses, and reduced reliability and cost effectiveness of the grid.

Coordinated charging strategies are the solution to eliminate the effects of high EV penetration on the grid by optimizing the charging time schedule and the amount of charging. For example, the rates of electricity will be cheap at night or at specific scheme when time of use (TOU) is available, a coordinated charging strategy will schedule and optimize the EV charging time to fit in with the TOU or when demand is low. Authors in [17] present an intelligent strategy to control the EV charging time associated with TOU price.

4. CHARGING METHODS

For charging of EVs, DC or AC systems can be used. There are different current and voltage configurations for charging, generally denoted as ‘Levels’. The time required for a full charge depends on the level being employed. Wireless charging has also been tested and researched for quite a long time. It has different configurations as well.

AC CHARGING

AC charging system provides an AC supply that is converted into DC to charge the batteries. This system needs an AC/DC converter. According to SAE EV AC charging power levels can be classified as Level 1, Level 2 and Level 3 and the characteristics of each level is represented in the following Table 2 defined by Society of Automotive Engineers (SAE).

Table 6. SAE (Society of Automotive Engineers) AC charging characteristics [18], [19]

AC Charging System	Supply Voltage (V)	Maximum Current (A)	Branch Breaker Rating (A)	Circuit Rating	Output Power Level (kW)
Level 1	120V, 1- Φ	12	15		1.08
	120V, 1- Φ	16	20		1.44
Level 2	208-240 V, 1- Φ	16	20		3.3
	208-240 V, 1- Φ	32	40		6.6
	208-240 V, 1- Φ	≤ 80	Per NEC 635		≤ 14.4
Level 3	208/480/600 V	150-400	150		3

DC CHARGING

DC systems require dedicated wiring and installations and can be mounted at garages or charging stations. They have more power than the AC systems and can charge EVs faster. Their classification is done depending on the power levels they supply to the battery. Table 3 shows the DC charging characteristics defined by Society of Automotive Engineers (SAE).

Table 7. SAE (Society of Automotive Engineers) DC charging characteristics [20]

DC Charging System	DC Voltage Range (V)	Maximum Current (A)	Power (kW)
Level 1	200-450	≤ 80	≤ 36
Level 2	200-450	≤ 200	≤ 90
Level 3	200-600	≤ 400	≤ 240

WIRELESS CHARGING

Wireless charging or Wireless Power Transfer (WPT) enjoys significant interest because of the conveniences it offers. This system does not require the plugs and cables required in wired charging systems, there is no need of attaching the cable to the car, low risk of sparks and shocks in dirty or wet environment and less chance of vandalism. However, this technology is not currently available for commercial EVs because of the health and safety concerns associated with the current technology. There are different technologies that are being considered to provide WPT facilities. Table 4 compares different wireless charging systems in terms of performance, cost, size, complexity, and power level.

Table 8. Comparison of wireless charging systems [21]

Wireless Charging System	Performance			Power Level
	Efficiency	EMI	Frequency	
Inductive power transfer (IPT)	Medium	Medium	10-50 kHz	Medium/High
Capacitive power transfer (CPT)	Low	Medium	100-500 kHz	Low
Permanent magnet coupling power transfer (PMPT)	Low	High	100-500 kHz	Medium/Low
Resonant Inductive power transfer (RIPT)	Medium	Low	1-20 MHz	Medium/Low
On-line inductive power transfer (OLPT)	Medium	Medium	10-50 kHz	High
Resonant antennae power transfer (RAPT)	Medium	Medium	100-500 kHz	Medium/Low

5. FUTURE TRENDS

Despite the low environmental impact and high energy efficiency, EVs have not been widely accepted by people to date. The lack of charging infrastructure is one of the reasons. However, as battery capacity and range of EVs are improved, and potentially some EVs in the future would need Level III fast charging to extend the driving range, there is an increased need to build off-board charge station infrastructures. Level 3 fast charging provides a method to alleviate range anxiety for the driver of passenger EVs. The need for recharging in the community and on highways preferably fast charging is essential for mass commercialization. Constraints on storage and charging problems can be relaxed with inductive roadbed charging systems, since a portion of the operational power is delivered from the roadway.

6. CONCLUSION

This paper reviewed the current status and implementation of EV battery charging infrastructure. Battery infrastructure and charging power levels are categorized into three types: Level 1, Level 2 and Level 3. Charger systems are categorized into off-board and on-board types with unidirectional and bidirectional power flow. Uni-directional charging limits hardware requirements, simplifies interconnection issues and tends to reduce battery degradation. Bi-directional charging supports battery energy injection back to the grid. Various charger power levels and infrastructure configurations were presented and compared based on the amount of power, charging time and location, cost, suitability, equipment necessary and other factors. Success of EVs depends on standardization of requirements and infrastructure decisions, efficient and smart chargers, and enhanced battery technologies.

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*Key words:
Bidirectional Charger, Vehicle-to-Grid,
Electric Vehicles, Renewable Energies, Energy Storage.*

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INTEGRATION OF ELECTRIC VEHICLES INTO POWER GRID: A STUDY ON VEHICLE-TO-GRID TECHNOLOGY

Global Warming and Increased Energy needs across the world has resulted in rapid development of Renewable energy sources and Electric vehicles. But the high unpredictability of Energy production with the Renewable sources leaves a big necessity for having a reliable Energy storage system which can be used for Peak shaving and to prevent the power grid from overloading. With Electric Vehicles seem to become the main form of transportation in the near future to curb the emission of Greenhouse gases, these can be a viable option as Energy storage system with the implementation of Vehicle to grid technology. The idea is to use the Electric vehicles (which can possibly become one of the largest electric loads on grid) as Energy sources for Power grid. Vehicle to grid technology provides bidirectional energy flow between electric vehicles and the power grid, which in turn providing various services to the Power grid such as power grid regulation, spinning reserve, peak load shaving, load levelling and reactive power compensation thus reducing the stress on the grid. Although this technology is still under development stage it can be regarded as a potential solution for the issue mentioned above. The Scope of the paper provides a brief study on the concept of Vehicle to grid technology, its advantages and awaiting challenges.

1. INTRODUCTION

Recently, the introduction of the smart grid concept has modernized the power system with additional communication features [1, 2]. Vehicle to Grid (V2G) technology is one of the main smart grid applications, which depends on the EV to improve the performance of power system. V2G technology can be categorized into unidirectional and bidirectional [3, 4].

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For unidirectional V2G, it utilizes the communication between the power grid operator and EV to throttle the charging rate of each EV. This action can prevent grid overloading, system instability and voltage drop issues [5, 6]. From the perspective of the power grid, EV battery is an electric load but also can be considered as energy storage. Therefore, bidirectional V2G utilizes this idea to enable energy exchange between the

EV battery and the power grid for EV charging or grid support. The bidirectional V2G provides greater flexibility for the power utility to control the EV battery energy to improve the reliability and sustainability of power system [7–9]. Section 1 gives an introduction on the V2G background. In Section 2, V2G concept and structure will be explained. The comparison between unidirectional V2G and bidirectional V2G will be discussed in Section 3. Section 4 and 5 provides the benefits and challenges of V2G technology respectively. A conclusion for the paper is given in Section 6.

2. VEHICLE-TO-GRID CONCEPT AND STRUCTURE

V2G refers to the control and management of EV loads by the power utility or aggregators via the communication between vehicles and power grid. There are three emerging concepts of grid-connected EV technologies, which are the Vehicle to Home (V2H), Vehicle to Vehicle (V2V) and Vehicle to Grid (V2G) [10]. V2H refers to the power exchange between the EV battery and home power network. In this case, EV battery can work as energy storage, which provides the backup energy to the home electric appliances and to the home renewable energy sources [11]. V2V is a local EV community that can charge or discharge EV battery energy among them. V2G utilizes the energy from the local EV community and trades them to the power grid through the control and management of local aggregator [12].

In general, V2H, V2V and V2G require components such as power sources, power loads, power grid aggregator, power transmission system, communication system, electric vehicles, and vehicle to grid chargers. The typical structure of a V2G system is shown in Fig. 1.

3. POWER FLOW FROM VEHICLE TO GRID

V2G refers to the interaction between electric vehicle and power grid with the assistance of the communication system. Power grid operator utilizes the communication facility to control and manage the power flow between the EV battery and the power grid in order to achieve desired benefits. In most cases, the objectives of the V2G management are to maximize profit, reduce emissions and improve power quality of the grid [13,14].

3.1 UNIDIRECTIONAL V2G

Unidirectional V2G is a technology that controls the charging rate of EV battery in a single power flow direction between the EV and grid [3,15]. The realization of the unidirectional V2G is inexpensive by adding the simple controller to manage the charge rate. Unidirectional V2G can provide ancillary services to the power grid, such as power grid regulation and spinning reserve [16,17]. This can enhance the flexibility of the power grid operations. However, unidirectional V2G does not provide enough services

to support the Power grid operation. These premium services such as peak load shaving, reactive power support, voltage regulation and frequency regulation can only be achieved by bidirectional V2G.

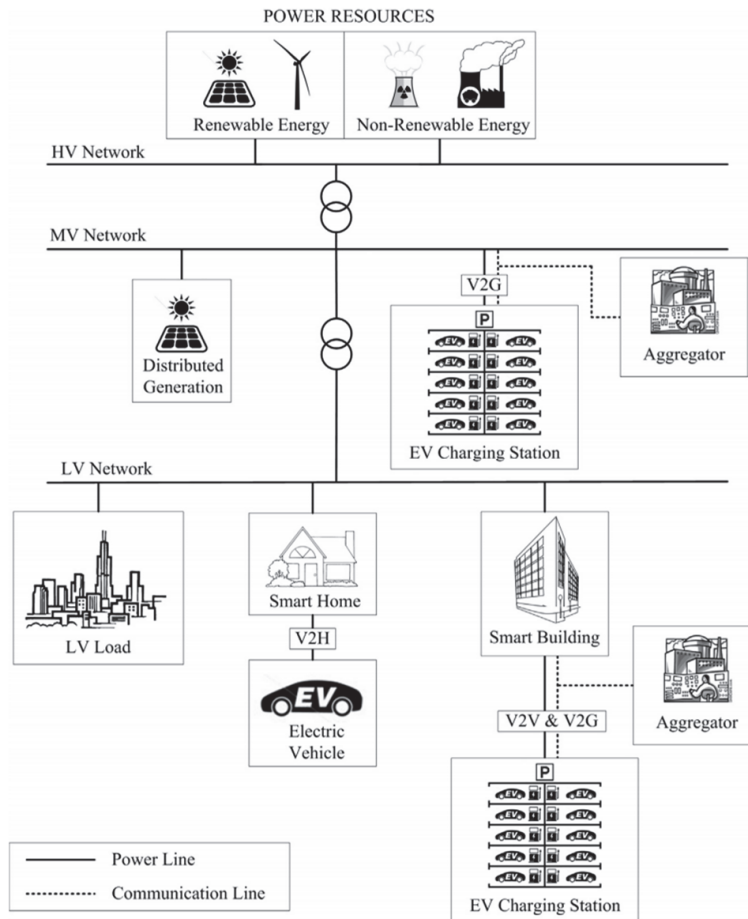


Fig. 11. V2H, V2V and V2G Structure [10].

3.2 BIDIRECTIONAL V2G

Bidirectional V2G refers to the dual direction power flow between EV and the power grid to achieve numerous benefits. A typical bidirectional EV battery charger consists of AC/DC converter and DC/DC converter as depicted in Fig. 2. The AC/DC converter is used to rectify the AC power from the power grid to the DC power during the EV charging mode and inverts the DC power to the AC power before injecting back to power grid in the discharging mode. On the other hand, the DC/DC converter is responsible in controlling the bidirectional power flow by using current control technique. The DC/DC converter acts as a buck or boost converter during charging or discharging mode, respectively. The main benefits are active power support, reactive power support, power factor regulation and support for the integration of renewable energy resources.

Active power support from bidirectional V2G can achieve peak load shaving and load levelling services [18].

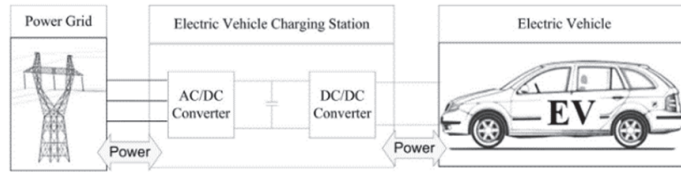


Fig. 12. Power flow diagram for V2G [18]

4. E ADVANTAGES OF V2G TECHNOLOGY

4.1 ACTIVE POWER SUPPORT

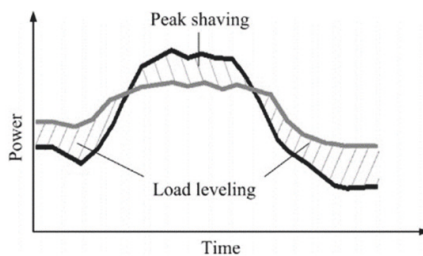


Fig. 13. Load profile comparison before and after peak load shaving and load [18]

V2G service utilizes the excessive EVs energy to provide active power support to the power grid. The active power support requires EVs to discharge the batteries energy and therefore, could only be accomplished using bidirectional V2G but not unidirectional V2G. The goal of this service is to flatten the grid load profile by “peak load shaving” and “load levelling”. Fig. 3. shows the comparison of a typical residential load profile before and after the implementation of peak load shaving and load levelling. EVs can be utilized to supply energy to the power grid during the peak load period to shave off the peak load. This can help to reduce the applied stress on power system components during the peak load period and the EV owners will be paid with a premium energy rate. During the off peak hours, EV owners can charge their EV batteries with lower energy price [18].

4.2 REACTIVE POWER COMPENSATION

Reactive power compensation is a technique to provide voltage regulation in the power grid. Reactive power support also provides power factor correction, which reduces the current flows from generation and power losses in power line. Furthermore, this service can reduce the loading of power equipment, which leads to the increase in power system operating efficiency [18]. In most cases, a capacitive reactive power is

needed for the power grid compensation. Therefore, grid-connected EV is able to provide the reactive power compensation service due to the capacitive reactive power reserved in the DC-link capacitor of the EV bidirectional battery charger. Since the reactive power compensation is provided by the DC-link capacitor of the EV bidirectional battery charger, this service will not cause any degradation to the battery lifespan. The reactive power compensation is done by controlling the switching of the AC/DC converter with various control strategies [19, 20].

4.3 SUPPORT FOR RENEWABLE ENERGY RESOURCES

The unpredictable and inconsistent energy production is the drawback of renewable energy resources. The integration of EVs in the power system can be a solution to the issues above. The intermittency issue of renewable energy resources can be solved by utilizing a fleet of EVs as energy backups or energy storages. The EV fleets act as the energy backups to supply necessary power when the renewable energy generation is insufficient. Meanwhile, they act as energy storages to absorb the excessive power generated by renewable energy resources, which would otherwise be curtailed. Research has shown that larger renewable energy capacity can be accommodated into the power system with more grid-connected EV battery capacity. Therefore, EV is able to improve the economics of the renewable energy generation industry. With proper energy management between renewable energy resource and EV, the future power grid will be cleaner and more sustainable [18].

5. 5V2G CHALLENGES

5.1 BATTERY DEGRADATION

Battery cells will deteriorate gradually under the battery charging and discharging cycles. The irreversible chemical reaction in the battery will increase the internal resistance and reduce the battery useable capacity [21]. The battery aging rate depends on many factors, which include the charging and discharging rates, voltage, DOD and temperature. Participations of EVs in the V2G technology require more battery charging and discharging cycles which are likely to result in quicker battery degradation. V2G control strategy and battery wear scheme are developed to prevent the abusive use of EV battery. Balance between the financial factor and the battery technical factor is crucial to optimize the benefits for power utility and EV owners [18].

5.2 HIGH INVESTMENT COST

Another challenge to the V2G implementation is the high investment cost required to upgrade the power system. Improvements in hardware and software infrastructure are needed for the V2G implementation. Each EV that participates in the V2G system will require a bidirectional battery charger. A bidirectional battery charger is the hardware

that consists of complex controller and high tension cabling with tight safety requirement. In addition, V2G has the potential to increase energy loss, which is another unfavourable issue in power system as it has a direct relationship to financial disadvantage. The V2G implementation requires frequent charge and discharge cycles and these processes involves energy conversions which will contribute to more conversion losses. Multiple energy conversions for a large fleet of EVs charging and discharging processes can denote serious energy losses to the power system [22].

5.3 SOCIAL BARRIERS

The participations of a large number of EVs are crucial requirements for the V2G implementation. However, the social barrier has prevented the public acceptance of the V2G technology, which appears to be a huge challenge for V2G adoption. In most cases, EV owners will ensure a guaranteed amount of energy stored in the EV battery for emergency use and unpredicted journey [6]. Since taking part in the V2G technology requires them to share the EVs batteries energy with the power grid, this will create the range anxiety among the EV owners [23]. The lack of charging facility makes the situation becomes worse. In order to reduce the social barriers for V2G implementation, a well-planned EV charging network is necessary. In addition, V2G management control needs to consider the EV SOC level. V2G connectivity needs to be cut off when the EV SOC is lower than an initially pre-set percentage [24]. This is to ensure the EV battery has enough energy for the daily driving usage [18].

6. CONCLUSION

This paper provides the framework, types, advantages and challenges of V2G operation. V2G is a new technology, which realizes power exchange between vehicle and power grid. The two types of this technology which are unidirectional and bidirectional V2G Categorized based on the power flow between EV and grid are discussed briefly. Both V2G types are able to provide numerous services to the power grid, such as peak load shaving, load levelling and as solution for the intermittent renewable energy availability issue. The foremost requirement to implement the V2G technology is the existence of the technologies related to it. Although there are numerous advancements in the Practical EV battery and V2G charger, they are still in development stage. Besides, V2G technology implementation requires EV charging station network and bidirectional communication infrastructure. Nonetheless, both Electrified transportation and V2G technology are inevitable as they provides numerous environmental benefits and services to the Grid respectively. However, the realizability of V2G technology depends on active participation and collaboration of government, power utilities, V2G aggregators and EV owners. Optimised V2G management system with incentive-based policy is vital for catalysing the success of this technology.

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Keywords: Fuel Cell Technology, Fuel cell Hybrid Electric Vehicle.

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Dhileep Reddy PATHI

FUEL CELL HYBRID ELECTRIC VEHICLE TECHNOLOGY AND SIGNIFICANCE ON ENVIRONMENT

Hybrid electric vehicles (HEVs) have great potential to save fuel consumption and reduce pollution emission, so many researches have focused on the technologies and applications of HEVs both in academia and industry to make the carbon emission curve decrease. It indicates that the share of HEV'S will be 58% by the end of 2040. Transportation is also making its change by introducing hybrid Electric Vehicle. some European countries have already established support schemes for the public and companies to move towards HEV'S. This paper presents the technology involved in Fuel Cell Hybrid Electric vehicles and how Fuel cell energy is different from other energy sources of Vehicles. Overview of a Fuel Cell Hybrid Electric Vehicle (FCHEV) and what makes it a zero-carbon emission vehicle. The significance on the environment will be highlighted.

1. INTRODUCTION

Renewable energy generation and Electric Vehicles (EVs) are the new trends to overcome the problems of abrupt environmental change, air pollution, and energy issues. In the new direction of development, EV makers could practically increase by a factor of four that can be achieved by 2020, moving to 4.5 million units that are 5% of the general worldwide light-duty vehicle advertise. The primary obstacle forms the customer perspective, are the vehicle mileage, charging duration, lack of charging stations, and generally high price as compared to other conventional vehicles [1]. To handle these issues, potential proposals have been examined, for example, improvement in the batteries and their materials, battery substitution, remote charging, and coordination green energy sources [2]. This significantly reduces the dimensions and price of batteries, which remain downsides of the standing EV charging [3] and drives down consumer demand for EVs. Without a doubt, these days, fuel cells have been now and again utilized in electrical vehicles as a result of their potential energy source, work under low temperature, and, essentially their energy density [4]. It will be necessary to use to consolidate, in any event, two energy sources: one major and other auxiliaries [5]. In this paper, we will discuss the Fuel cell technology, Propulsion using Fuel, an overview of the Fuel cell Electric Vehicle and the impacts of the Fuel cell vehicles on the Environment.

2. FUEL CELL

2.1. OVERVIEW

Fuel Cells are electrochemical devices that convert the chemical energy of a gaseous fuel directly into electricity and are widely regarded as a potential alternative stationary and a mobile power source. They complement heat engines and reduce the ubiquitous dependence on fossil fuels and thus have significant environmental and national security implications. Fuel cell efficiency is high at partial loads which correspond to the majority of urban and highway driving scenarios. Transient behaviour is a key requirement for the success of fuel cell vehicles. The fuel cell system power response is limited only by the air and hydrogen feed, flow and pressure regulation, and heat and water management. As current is instantaneously drawn from the load source connected to the fuel cell stack, heat and water are generated, whereas oxygen is depleted. During the transient, the fuel cell stack breathing control system is required to maintain optimal temperature, membrane hydration, and partial pressure of the reactants across the membrane to avoid detrimental degradation of the stack voltage, and thus, efficiency reduction. These critical fuel cell parameters can be controlled for a wide range of current, and thus power, by a series of actuators such as valves, pumps, compressor motors, expander vanes, fan motors, humidifiers, and condensers. The differences in cell characteristics, such as cell material, operating temperature, and fuel diversity, make each type of fuel cell suitable for different applications.

2.2. FUEL CELL REACTION

A fuel cell consists of an electrolyte sandwiched between two electrodes. The electrolyte has a special property that allows positive ions (protons) to pass through while blocking electrons. Hydrogen gas passes over one electrode, called an anode, and with the help of a catalyst, separates into electrons and hydrogen protons as shown in Fig. 1. The protons flow to the other electrode, called a cathode, through the electrolyte while the electrons flow through an external circuit, thus creating electricity. The hydrogen protons and electrons combine with oxygen flow through the cathode and produce water. The corresponding reactions are shown in Fig.1. The overall reaction of the fuel cell is, therefore [6]

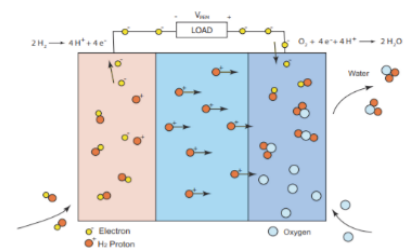


Fig. 14. Fuel Cell reaction [6]



The voltage produced from one cell is between 0 to 1 volt depending on fuel cell operating conditions and the size of load connected to the fuel cell. The typical value of

the fuel cell voltage is about 0.7 volts [6]. To get higher voltage, multiple cells are stacked in series. The total stack voltage is the number of cells multiplied by the average cell voltage.

2.3. STRUCTURE OF FUEL CELL IN AUTOMOBILE

It is known that Polymer Electrolyte Membrane Fuel Cells (PEMFC) are suitable for automobile applications. PEM fuel cells have high power density, a solid electrolyte, long life, as well as low corrosion. PEM fuel cells operate in the temperature range of 50 - 100°C which allows safer operation and eliminates the need for thermal insulation. The polymer electrolyte membrane is an electronic insulator but an excellent conductor of hydrogen ions. Depending on membrane manufacturers and the versions of the membrane, the properties of the membranes differ. The thickness of the membrane varies from 50 to 175 microns, which is approximately 2 to 7 papers thick [6]. The membrane is sandwiched between two electrodes (anode and cathode) made from a highly conducting material such as porous graphite. A small amount of platinum is applied to the surface of the anode and cathode to help increase the rate of reaction.

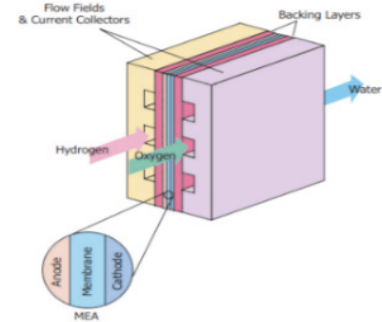


Fig. 15. Fuel cell Structure [6]

The three components (anode, electrolyte, and cathode) are sealed together to form a single membrane electrolyte assembly (MEA), shown in Fig. 2., which is typically less than a millimetre thick. The MEA is sandwiched by two backing layers made from porous carbon. The porous nature of the backing layer ensures effective diffusion of each reactant gas to the catalyst site on the MEA [6]. The outer surface of the backing layer is pressed against the flow field plates which serve as both reactant gas flow field and current collector. The plate is made of a light-weight, strong, gas impermeable, electron conducting material such as graphite or composite materials. The other side of the flow field plate is connected to the next cell. The number of cells stacked in one fuel cell stack depends on the power requirement of the stack, which varies across different applications. Depending on its operating condition, a single fuel cell can provide a voltage from 0 to 1.0 volts with a nominal value of 0.7 volts. By connecting a stack of fuel cells in parallel or series we can get a Fuel cell stack of higher voltage and current rating.

2.4. FUEL CELL PROPULSION SYSTEM FOR AUTOMOBILES

In order to be used to power an automobile, a fuel cell stack needs to be integrated with other components to form a fuel cell system. The diagram in Fig. 3 shows the minimal components required for a pressurized fuel cell engine [6]. The fuel cell stack requires four flow systems: (i) hydrogen supply system to the anode (ii) air supply system to the cathode (iii) de-ionized water serving as a coolant in the stack cooling channel and (iv) de-ionized water supply to the humidifier to humidify the hydrogen and the air

flows. These four subsystems are denoted by control inputs u_1 to u_4 in Fig. 3. Operation at high pressure significantly improves the reaction rate, and thus, the fuel cell efficiency and power density [6], a compressor, and an electric drive motor are needed to compress air to a desired pressure level. Due to high temperature of the air leaving the compressor, an air cooler is needed to reduce the air temperature before it enters the stack. A humidifier is used to add vapor into the air flow, in order to prevent dehydration of the membrane. As the air leaves the stack, it carries vapor produced in the fuel cell.

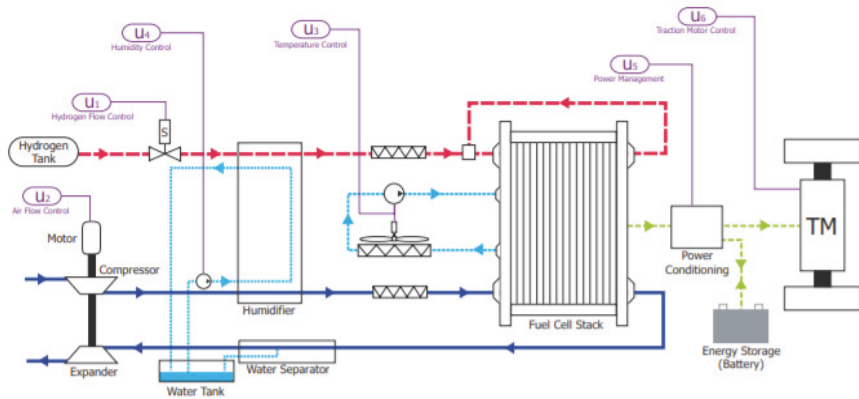


Fig. 16. Automotive Fuel cell propulsion [6]

For an automotive fuel cell system, a water separator is needed to recover the water. On the anode side, hydrogen is supplied from a container which can store pressurized hydrogen or liquid hydrogen. A valve is used to control the flow rate of hydrogen. A humidifier is also used to humidify the hydrogen flow. Since the temperature of the stack must be maintained below 100 °C for the membrane to be properly humidified, excessive heat released in the fuel cell reaction is removed by a de-ionized water coolant [6]. As illustrated in Fig. 3, the coolant leaving the stack then passes through a heat exchanger or a radiator to remove heat from the system. A power conditioner denoted as control input u_5 in Fig. 3, is frequently needed since the voltage of the fuel cell stack varies significantly and is not suitable for typical electronic components nor traction motors. The control input u_6 in Fig. 3 represents the control of traction motor drive. Reactant flow rate, total pressure, reactant partial pressure, temperature, and membrane humidity are the main parameters that need to be regulated in order to ensure (i) fast transient response, consistent warm-ups, and safe shutdown and (ii) robustness and adaptation to changing power. The main control devices are the compressor motor for the air flow and pressure regulations, the valve for hydrogen flow rate and pressure regulations, the water pump or radiator fan speed for the temperature regulations, and the humidifier for the humidity control. However, the changes in the parameters are not independent. Changes in one parameter influence the others. For fuel cell vehicles to be commercialized, these vehicle operations need to be well handled.

3. FUEL CELL HYBRID ELECTRIC VEHICLE

HEVs with a Fuel cell as primary energy source and battery, SC as a secondary energy source, are designed to provide power for short durations of peak power demand, such as during driving uphill or acceleration. Good acceleration requires both high power density and high energy density. Thus, having both battery and SC is essential because the SC has high power density and low energy density, whereas the battery has low power density and high energy density, respectively. In this vehicle, the energy is shared among the fuel cell, battery, and/or SC with the energy drawn from one, two, or even three energy sources. The drawn energy is used to rotate the traction motor using a power electronic interface. The co-ordination of these components requires an energy management system.

3.1. FUEL CELL

Fuel cells are electrochemical devices which convert chemical energy into electrical energy directly by oxidizing hydrogen without intermediate thermal or mechanical processes. Proton exchanges membrane fuel cells (PEM-FC) are usually preferred in automotive applications because they are compact and they have a short start-up [8].

3.2. BATTERY

There are many types of batteries in the market, however, the most commonly used in electric vehicles would be the NiMH and Li-ion batteries [9]. On one hand, NiMH batteries are considered environmentally safe, low maintenance, has high power and energy density, and considerably cheap. On the other hand, Li-ion batteries, are light, compact, have more energy storage than the NiMH, but have a wide range of operational temperatures and there are concerns regarding the availability of materials.

3.3. SUPER-CAPACITOR

The reason for considering a super-capacitor (SC) in the vehicle setup is its high specific power rate and its ability to accept a full recharge/charge in a very short time, which leads to an improvement in vehicle efficiency and energy economy. The use of a super-capacitor is especially beneficial if braking energy has to be recovered [8].

3.4. MOTOR

The motor would be the actuator for the conversion of electrical energy into kinetic energy. The motor can either be an AC or a DC motor depending on the input power fed into the machine. Among the common motors used for electric vehicles are induction motors, permanent magnet brushless motors, and switched reluctance motors [9].

3.5. ENERGY MANAGEMENT SYSTEM

As the vehicle uses a Fuel cell system, Battery, and SC system as energy sources to cater to its energy demand or requirement, an efficient Energy management system is mandatory to perform the Energy Management task effectively i.e., to manage the Power flow from sources to the drive system and auxiliary systems in an efficient way. The EMS still needs to be further explored and developed in terms of hardware or real-time applications to ensure the reliability of a fuel cell HEV.

3.6. POWER ELECTRONIC INTERFACE

The fuel cell produces low DC voltage by adjusting the fuel cell to a level with the DC bus voltage by a suitable DC-DC converter. DC-DC converters for fuel cells should be able to buck or boost voltages in one direction only because there is no charging of fuel cells. Meanwhile, DC-DC converters for the battery and SC should be able to buck and boost voltages for the charging and discharging mode. Hence, buck-boost converters are usually used for the battery and SC [9]. The DC voltage is then fed to the Traction motor using a power electronic converter. Here in this paper, we have considered an AC motor, so the DC bus voltage is converted to AC power using and DC/AC inverter.

3.7. FUEL CELL HYBRID ELECTRIC VEHICLE INTERFACE

The FC produces a low voltage, which is made usable by two DC/DC converters. One converter transfers power to the auxiliary loads such as water, fuel and air pumps, ventilation, and control systems. Another converter transfers power to the input DC bus of traction motor inverter. The Energy Storage System (ESS) system is interfaced to the DC bus by a bidirectional converter. The traction motor inverter produces AC from the DC power supplied by FC and ESS, and the traction motor uses the AC power to produce mechanical output used to drive the wheel of the vehicle. This system is a hybrid arrangement, which utilizes the regenerative braking power of the traction motor. The ESS also works as a power source during the initial start-up of FC. Once the fuel cell is warmed up, the ESS supply is turned off and the system runs by FC solely [7]. The traction motor will produce the mechanical energy required to move the vehicle. The energy management system will coordinate all the components to achieve high efficiency, reliability, cost-effectiveness, and smooth operation of the FCHEV. The schematic of the vehicle is shown in Fig. 4.

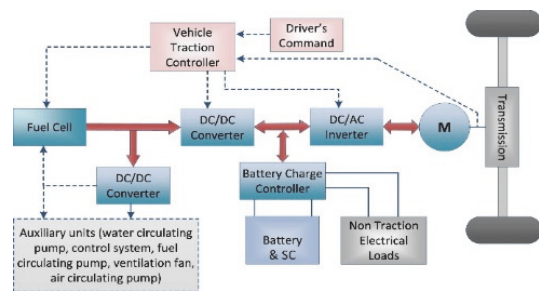


Fig. 17. Schematic of the Vehicle [7]

4. ENVIRONMENTAL IMPACT

FCHEVs are more energy-efficient than ICEVs or HEVs. They have several environmental benefits, such as low pollution level, low noise level, low-temperature system, production of water, saving in fossil fuels due to high efficiency and good part-load [7]. FCHEVs have almost no environmental impact; with main advantages from an environmental point of view as low greenhouse gas emissions, reduced oil dependence, and less air pollutant emission. Producing hydrogen in an economical, efficient, and sustainable way is another challenge. One of the production processes i.e., hydrogen produced from electrolysis. In order to make the process zero CO₂ emission, the energy required for electrolysis can be supplied from renewable sources like wind and solar when excess energy is captured.

5. FUTURE PROSPECTS

FCHEVs can play a significant role in the future vehicle market. It can be a strong contender to conventional ICE vehicles. It is assumed as certain that if the performance of FCHEV is competitive with the ICEV, people will choose FCHEVs [7]. Researchers have done cost prediction analysis to predict the cost of FCHEV in near future [7]. The prediction shows that the capital cost of FCHEV will be competitive with ICEV in the near future. The running cost is also predicted from the analysis, where the average fuel cost in 2030 for gasoline, hydrogen, and electric will be 28.5 \$/Gj, 35 \$/Gj, and 36 \$/Gj respectively. The mileages for the same fuels are 40 mpg, 72 mi/kg, and 3.6 mi/kWh, respectively, which means hydrogen price is competitive to gasoline and the running cost will be lower than gasoline [7]. These predictions open wide the prospects for FCHEVs in the future.

6. CONCLUSION

The need for reduction of greenhouse gas emissions in the automotive field resulted in evolution of Fuel Cell Hybrid Electric Vehicle (FCHEV). This study aims to present the state of art of FCHEV its, technology, propulsion system and components. A slight insight into the environmental impacts and future prospects of the Fuel cell hybrid electric vehicle has been illustrated. This technology has a potential to lead as an alternative in the sustainable mobility. Upward trends in improvement of hydrogen infrastructure are evident. Innovations in the areas of facilitating regenerative braking, maximizing efficiency and improvements in transient performance of FC in the vehicle system can make it a promising solution for future mobility.

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*Key words:
Wave Energy Converter, Pelamis, Hydraulic Ram,
Renewable Energy Source, Wave Power.*

Paresh CHAUHAN

PELAMIS WAVE ENERGY CONVERTOR – TECHNIQUE FOR ENERGY GENERATION

The world's attention on renewable energy generation is heavily focused on wind, solar, geothermal, wave and the new field of ocean current, tidal and river power. Presently, the European Union is mainly focusing on energy generation from renewable sources. Oceans consists of more than 70% of the earth surface, and it has the potential to compete with the coal-powered plant and provide stability to the grid in case of baseload efficiency.

Sea waves are associated as a form of renewable energy source which can be captured using the hydro-mechanical devices which produce electrical energy by driving an electrical generator. A device that can harness wave power and convert it into and electrical power are known as Wave Energy Converter. The main objective here is to study wave energy as an energy source whose capture is still developing. The energy obtained from the ocean waves is 100% renewable than nuclear, coal, thermal, etc., in terms of environmental impact. The technology studied here is the Pelamis Wave Energy Converter.

1. INTRODUCTION

Due to the shortage of resources, conventional power plants cannot fulfil the increasing power demand. To build the gap of the rising power demand can be fulfilled by renewable energy sources. There are various renewable energy sources like solar, wind, biofuels, geothermal, wave energy, etc. Since most energy sources are intermittent, we cannot get a continuous supply of energy from them. Global theoretical energy from waves is 8×10^6 TWh/year, which is 100 times the total hydroelectricity generation of the whole planet. Using fossil fuel to generate such a massive amount of energy would result in 2 million tons of CO₂. Wave energy can help attenuate pollutant gases in the atmosphere, as defended by the Kyoto Protocol[1].

Thermal based, wave-based and current-based are the technologies used to harness the energy contained in the sea. Wave and current-based devices harness the waves' potential and kinetic energy. In a thermal-based converter, differences in the water temperature of different depth are converted into valuable energy[2]. Pelamis is a device that generates electricity by harnessing the predictable motion of ocean surface waves. It is a wave-based ocean energy conversion and a semi-submerged device that operates in water depths greater than 50m. Thus, the paper aims to study the Pelamis wave energy capture methods, their working principle, installation system.

2. OPERATION AND WORKING PRINCIPLE

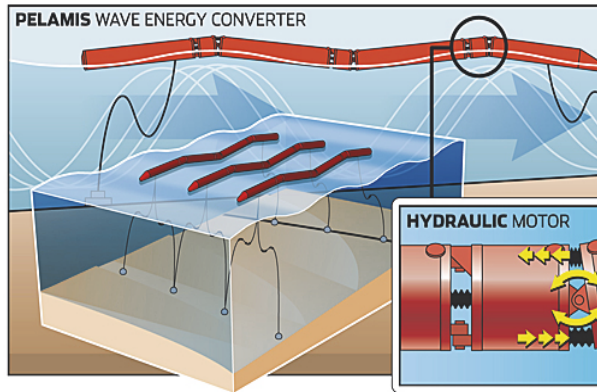


Fig 1: Cross-sectional view of Pelamis WEC

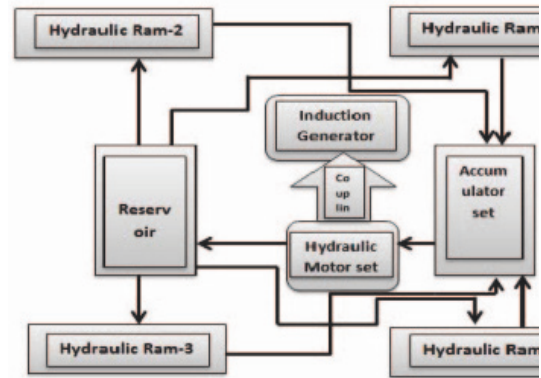


Fig 2: Block Diagram of Pelamis WEC[4]

In Fig 1. We can see that the machine (Pelamis) consists of a series of semi-submerged interconnected cylindrical sections connected by a U-joint, which follows the wave's curvature [3]. To utilize the maximum wave energy, it should follow the yaw mechanism with the tide. When a wave passes along the machine's length, it starts to move upward and downward relatively. The cylindrical section is connected to the hydraulic ram, which converts the wave's energy into hydraulic energy by pumping the high-pressure oil through a hydraulic motor via a smoothening hydraulic accumulator. The hydraulic motor then drives the electrical generator, which produces electricity.

Fig 2. shows the internal working of the Pelamis. When waves pass along the machine length, hydraulic ram-1 and hydraulic ram-2 begins to push hydraulic fluid (oil) into the accumulator set. The accumulator's function is to absorb the high-pressure shocks and to smooth the hydraulic rams' pressure. Simultaneously, hydraulic ram-3 and hydraulic ram-4 retracts, which causes the sucking of hydraulic fluid from the reservoir. The pressurized fluid from the accumulator goes to the hydraulic motor set via the inlet port. The hydraulic motor set utilizes the liquid's pressure, which rotates the rotor and exhaust at low pressure via an outlet port into the reservoir. Since the hydraulic motor is coupled to the generator, it starts to turn and generates power. During the negative half cycle of the cylindrical section, hydraulic ram-3 and hydraulic ram-4 are in action and pushes the fluid into the accumulator set via the inlet port. Accumulator supplies the high pressurized fluid to the motor set to maintain the rotation of the hydraulic motor set for generating power continuously. During this action, hydraulic ram-1 and ram-2 sucks low-pressure fluid from the reservoir[4].

3. METHODOLOGY FOR ENERGY CAPTURING

3.1. WAVE POWER FORMULA

The water depth is more significant than half of the wavelength in deep waters; the wave energy flux is given by [5][6]:

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T_e \approx (0.5 \text{ KW}/m^3 s) H_{m0}^2 T_e \quad (1)$$

Where,

P = Wave Energy Flux/unit of wave crust length (KW/m),

H_{m0} = Wave Height in meters(m), T_e = Wave Energy Period in seconds (s),

ρ = Density of sea water (kg/m^3), g = Gravitational Acceleration(m/s^2).

When the wave period is in seconds, and the wave height is in meters, wave power is in kilowatts per meters.

3.2 WAVE ENERGY AND WAVE-ENERGY FLUX

According to Airy wave theory (linear wave theory) [9], the mean energy density per unit area of gravity waves on the surface of the water is proportional to the square of the wave height in a sea state[6][7][8]:

$$E = \frac{1}{16} \rho g H_{m0}^2 \quad (2)$$

E = Average energy density per unit horizontal area (J/m^2), the sum of potential and kinetic energy density/unit flat area. Kinetic energy = Potential energy [9], both contributing $\frac{1}{2}$ to wave energy density. The surface tension effect can be neglected for wavelength up to few decimeters for ocean waves.

$$P = E c_g \quad (3)$$

Energy is transported as wave propagates. The velocity with which the energy is transported is the group velocity (c_g) in m/s. Wave energy flux, through vertical plane of unit width perpendicular to the direction of propagation of wave is equal to: [9][10]

4. COMPONENTS OF PELAMIS

4.1. POWER CONVERSION MODULE

Power conversion modules (PCMs) connect the four individual steel tubes forming a Pelamis device. Each PCM contains a heave and sway joint. The modular power-pack is housed in a second fully sealed compartment behind the rain bay so that in the event of seal failure, only the hydraulic rams are immersed. Maximum individual component weight is less than 3 tons to allow replacement using light lifting equipment. Here, the hydraulic rams are used as pumps and used to resist each joint's wave-induced motion. The oil is pumped into the accumulator, which then drains into a hydraulic motor coupled to an electric generator. An oil—to—water heat exchanger is included to dump excess power in large seas and provide the necessary thermal load in the event of losing the grid. Overall power conversion efficiency ranges from around 70% at low power levels to over 80% at full capacity.[11]

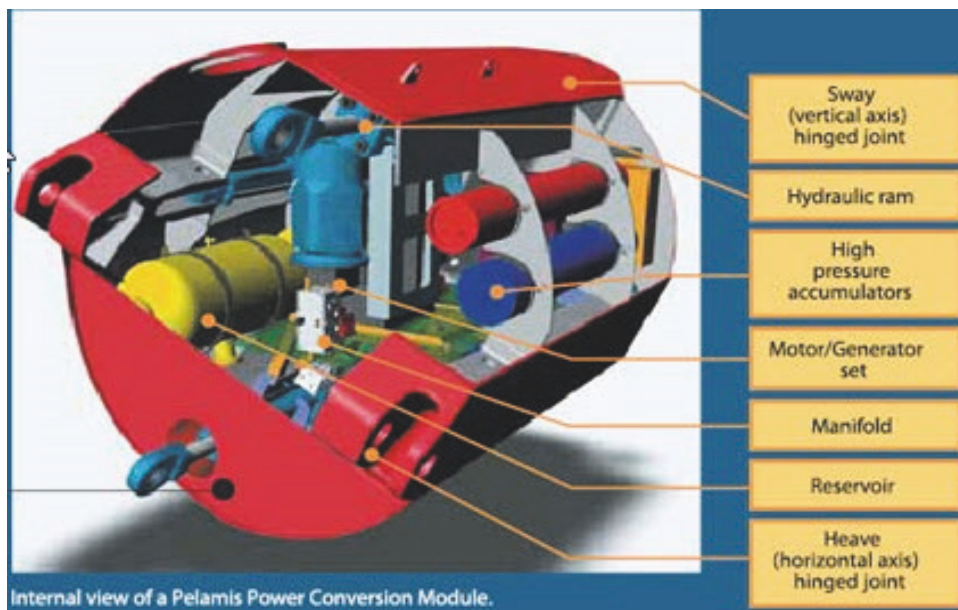


Fig 3. Power Conversion Module [14]

4.2. MOORING SYSTEM

The mooring arrangement of Pelamis needs to be designed specifically for the site conditions. Like a wind turbine foundation, which needs to be type-approved, the Pelamis mooring system needs to be designed by OPD and adapted to specific site conditions. Survival conditions, maximum current velocity, water depth, seafloor soil densities and other factors will need to be considered in a detailed design phase.[12] For this project's purpose, the reference mooring system used for Ocean Power Delivery prototype testing was used to establish a costing base case as shown in the above figure.

The mooring system of Pelamis is of a catenary type that uses a combination of steel wires, chains, deadweight and embedment anchors.

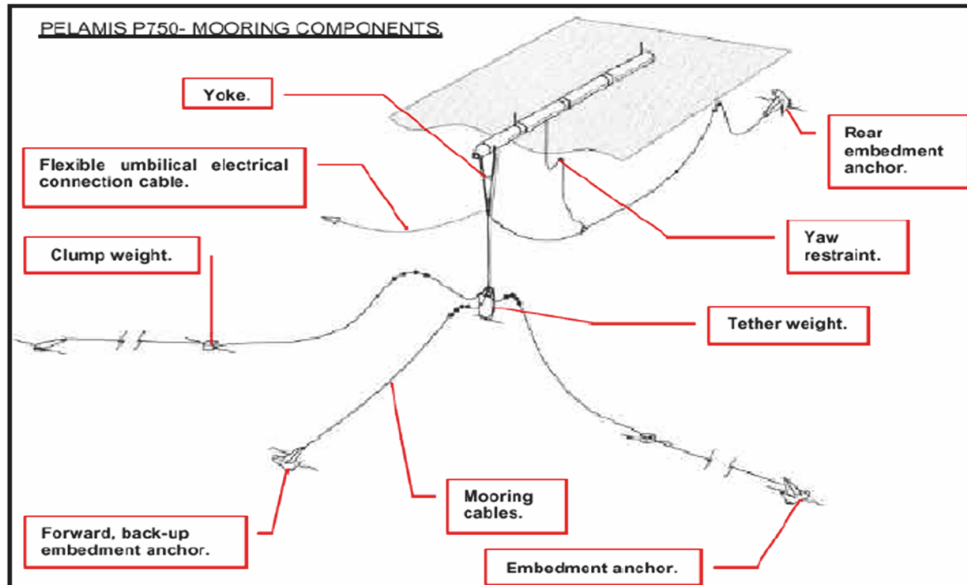


Fig 4: Details of the Mooring System.[13]

4.3. ELECTRICAL INTERCONNECTIONS

Each Pelamis device houses a step-up transformer to increase the voltage from generator voltage to a suitable wave farm interconnection voltage. The voltage level choice is driven by the grid interconnection requirements and the wave farm electrical interconnection design. A flexible riser cable is connecting the Pelamis to a junction box, sitting on the ocean floor. If multiple devices are connected together, they are daisy-chained by a jumper cable that runs from one device to the next. Only at specific strong-points, the electrical cord is then brought to the ocean floor. Due to this the number of riser cables is reduced and makes the cabling more accessible for maintenance from the die surface. Riser and jumper cables undergo many cyclic loadings, and they will likely need to be replaced after ten years of operation.

5. P2 PELAMIS

The operational and the design experience of the P1 machine led to the improved development of the P2 design program:

- By using new joint configuration which allows more efficient use of structure, drive train component, higher degree of modularity making the machine easy for its assembly.

- Increasing power capture and survivability margin by increasing the joint angle range.
- higher conversion efficiency of 20–30% and substantially lower cut in wave height (nominal 1 m Hs versus 2 m Hs) to keep absorbing in smaller seas common in summer.
- 35 per cent higher yield from the additional cylindrical machine section and associated length, along with a 15 per cent increase in diameter.

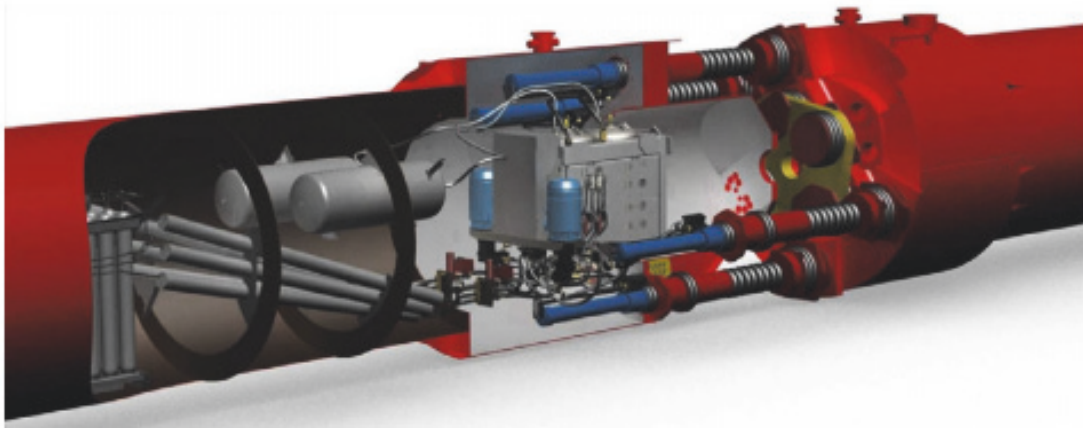


Fig 5: Cutaway section of P2 joint and power take-off. High pressure accumulators used to store the energy are also visible.[15]

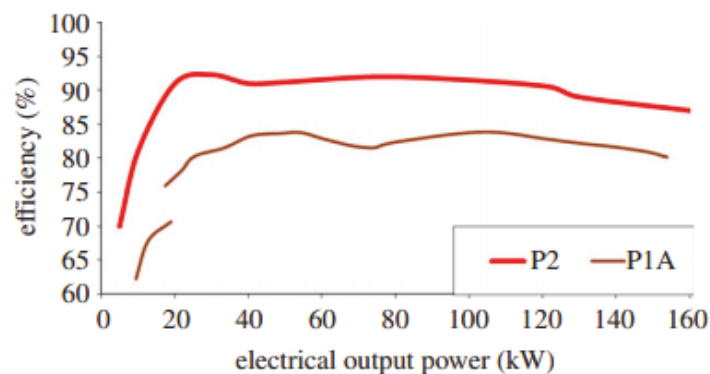


Fig 6: Power conversion efficiency Vs Output power.[15]

Above Fig 6. indicates the measured conversion efficiency of motor-generator set against power output that converts high pressure in the accumulator into electricity. The design improvement applied to P2 machine as compared to P1 machines can be seen both in terms of absolute efficiency and range. Total combined efficiency for P2 machine is approximately 70%.

Although all the fundamental design principle of P2 machine is similar to P1 machine the above improvements made results into almost 50 % higher yield per tonne than the P1 machine.

6. CONCLUSION

We know that wave energy is easy to operate and maintain but when it comes to energy generation from waves it has a very high potential. Energy from ocean wave is abundant if it is harnessed using suitable device which can solve the present electricity demand and clean energy can be generated from this source. Generation capacity mainly depends upon the intensity of the waves and the suitable location where waves are consistent and sufficiently strong. If systems with wave energy proves to be economical and successful, then only 0.1 % of the renewable energy can supply up to five time the global electricity demand.

Pelamis WEC is one of the options that helps in reducing the per gram CO₂ /kwh levels. Pelamis has a power takeoff system which is one of the devices of this kind. Pelamis WEC is a revolutionary concept resulting into many years of engineering research and development. It was the world's first commercial scale machine that generated electrical energy into the grid. In India the first WEC was installed at Vizhinjam working on the OWC principle in the world.

Usually wave energy convertor are installed several kilometers away from the shore or at island which makes it suitable for operation without depending on other countries electrical demand. For increasing power generation capacity and power quality, it is preferred to use intelligent controllers and power electronic converters. In developing countries to meet electrical demand, technologies like Pelamis WEC are important.

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Key words:
Battery Technologies, Alternative Fuels,
Lithium-ion Battery, Solid State battery, Fuel cells.

Karthik Reddy SOLIPURAM

Poornima TUMKUR NATARAJ

ALTERNATIVE FUELS FOR VEHICLES AND LITHIUM-ION BATTERY TECHNOLOGIES FOR ELECTRIC VEHICLES: IMPACT ON ENVIRONMENT

Depletion of oil reserves and reliability on their supply is uncertain and the issue is escalated with effects of climate change leading to environmental catastrophes. Europe is increasingly looking at alternatives to traditional road transport technologies. Battery Electric Vehicles (BEVs) are a promising technology, which could lead to the decarbonisation of the Light Duty Vehicle fleet and to independence from oil. However, it still must overcome some significant barriers to gain social acceptance and obtain appreciable market penetration. This review evaluates the Lithium-ion and the contemporary variant of Lithium based Solid State Battery, their challenges and impact on environment. Though moving on to EVs look great for now, the exploitation of Lithium mines will push for focus on alternate fuels. Newly developed clean fuel technologies such as Hydrogen, ammonia powered fuel celled vehicles are discussed.

1. INTRODUCTION

Electric vehicles are expected to account for 10–12% of the total automotive sales by 2030, according to industry expectations. Multiple factors that are driving the uptake of Electric Vehicles (EVs) include favourable regulations in Europe, China, and India; Technological advancements in batteries are one of the major driving factors for the adoption of electric vehicles. Currently, the battery cost is around US \$220/kWh, which is expected to reduce over the next decade. Conventional liquid lithium-ion-based batteries account for most of the batteries used in EVs [1]. To reduce the cost of the battery in EVs, either the technology should improve to have a high energy density, or lithium prices should decline over the period. According to industry experts, prices of lithium-ion batteries are expected to remain high, which is a main hurdle in lowering the battery cost. The advancements in battery technologies such as metal-air, solid-state batteries are expected to substitute the conventional Lithium-ion batteries in the next few years. Solid-state battery shows promising results for its mass adoption in EVs.

2. LITHIUM-ION BATTERIES

2.1 OVERVIEW

Casting aside environmental considerations for a moment and looking at the basics of battery power versus fossil fuel, one big advantage to battery-powered electric vehicles (BEVs) is when it comes to energy efficiency. Where energy efficiency for internal combustion engines is between 20 and 60 %, an electric motor can be 60–80 % efficient. Whereas the drawback lies in energy density. The energy by mass of gasoline is 2 orders of magnitude greater, 2,000Wh/kg, compared to a modern Li-ion battery with only 200Wh/kg. In Li-ion batteries, it is the lithium ions that move from anode to cathode to release energy from the battery—and back again during the recharging period. This constant discharge/charge cycle process slowly degrades the capacity of the battery. To make the battery last long, the three best ingredients for cathodes and anodes are: cobalt, nickel, and graphite. And therein lies the problem. Extraction of these minerals is neither eco-friendly nor safe for miners. EVs and their composition for batteries are on the threshold of leading to turmoil in the world's metal markets.

2.2 COMMONLY USED LI-ION BATTERIES IN EV'S-NCA

The lithium nickel cobalt aluminium oxides (NCA) are a group of substances comprising metal oxides. NCAs are used as active material on the cathode. NCAs are oxides comprising the cations of the chemical elements lithium, nickel, cobalt and aluminium. The most important representatives have the general formula $\text{LiNi}_x\text{Co}_y\text{Al}_z\text{O}_2$ with $x + y + z = 1$. In case of the NCA comprising batteries currently available on the market, which are also used in electric cars, $x \approx 0,8$.

NCA Properties: The charge storage capacity of NCA is about 180 to 200 mAh/g. This is well below the theoretical values; for $\text{LiNi}_{0,8}\text{Co}_{0,15}\text{Al}_{0,05}\text{O}_2$ this is 279 mAh/g. However, the capacity of NCA is significantly higher than that of alternative materials such as lithium cobalt oxide LiCoO_2 with 148 mAh/g, lithium iron phosphate LiFePO_4 with 165 mAh/g and NMC $\text{LiNi}_{0,33}\text{Mn}_{0,33}\text{Co}_{0,33}\text{O}_2$ with 170 mAh/g. NCA belongs to the cathode materials with layer structure, like LiCoO_2 and NMC. Its high voltage enables it to be used in batteries with high energy density. Another advantage of NCA is its excellent fast charging capability. Disadvantages are the high costs and the limited resources of cobalt and nickel. NCA and NMC materials have related structures, similar electrochemical behaviour, relatively higher energy densities and higher performance. Nickel-rich NCA— Advantages and limitations: NCAs $\text{LiNi}_x\text{Co}_y\text{Al}_z\text{O}_2$ with $x \geq 0.8$ are called nickel rich; The nickel-rich variants are low in cobalt and therefore have a cost advantage, as cobalt is relatively expensive. As the

nickel content increases, so does the voltage and thus the energy that can be stored in the battery. However, as the nickel content increases, the risk of thermal breakdown and premature aging of the battery also increases. When a typical NCA battery is heated to 180 °C, it will thermally run away. If the battery was previously overcharged, thermal run away can occur already at 65 °C. To make NCA more resistant, for batteries that need to operate at temperatures above 50 °C, the NCA active material is usually coated. The coatings may comprise fluorides such as aluminium fluoride AlF_3 , crystalline oxides (e.g. CoO_2 , TiO_2 , NMC) or glassy oxides (silicon dioxide SiO_2) or phosphates such as FePO_4 .

3. SOLID STATE BATTERIES

Solid-state batteries which use both solid electrodes and electrolytes can be a potential alternative to conventional lithium-ion batteries, which use liquid or polymer electrolytes. Solid-state batteries offer high performance and safety at low cost and thus are an emerging trend for next-generation traction batteries. Additionally, they have low flammability, higher electrochemical stability, potential cathodes, and higher energy density as compared to liquid electrolyte batteries. Polyether and Lithium Phosphorus Oxy-nitride (LiPON)-based electrolytes are commonly used in solid-state batteries.

3.1 ADVANTAGES AND CHALLENGES IN SOLID STATE-BATTERIES

Solid-state batteries are smaller in size as compared to liquid lithium-ion batteries. They do not produce hydrogen gas due to the absence of flammable materials, thereby strengthening the operational safety. Solid-electrolyte Interfacial Layer (SEI) is not formed in case of solid-state batteries, which results in very low self-discharge rates allowing multi-year power storage with minimal loss. These batteries are expected to operate 50–100 times longer than conventional liquid lithium-ion batteries [2]. Currently available solid-state batteries face a challenge in terms of operating life, which is approximately three years. Research & development activities help extend the operating life of solid-state batteries for more than three years so that they can be fully commercialized for electric vehicles.

The restraining factors affecting the uptake of EVs can be overcome using solid-state batteries, as they fulfil the energy and technical requirements of electric vehicles. **Energy density:** can be increased per kg as solid-state batteries are 80–90% thinner, and the decomposition voltage is high as compared to lithium batteries. **Safety issues:** Liquid electrolytes are generally flammable, and any leakage of these would lead to safety concerns of batteries and overall vehicles. As solid-state batteries use flame retardant electrolyte, there is very less risk of fire and flammability. **Fast charging:** Solid-state batteries do not contain a liquid electrolyte, which gets heated due to fast charging, and thus, solid-state batteries provide high safety as compared to liquid lithium-ion batteries. **Low cost:** Conventional liquid lithium-ion batteries are costly,

and the current cost is approximately US \$220/kWh. This cost is expected to reduce over a period; however, it is dependent on scarce materials such as cobalt. Research & development activities in solid-state batteries will contribute to the development of advanced batteries at an affordable cost.

4. CHALLENGES WITH LI-ION BATTERIES

Meeting Demand: Lithium consumption has been growing exponentially since the early 2000s and is, expected to quadruple again by 2025. Lithium is sold not as a pure element but as lithium carbonate. A 70kWh Tesla engine uses 63kg of lithium carbonate, the price of which doubled in 2017, compared to the year before to \$13.90 per kg. BEVs are now a global driving force of lithium demand by exponential proportion.

Impact of extraction: The lithium extraction process requires water in no small amount to bring the element up to the surface in a salty brine—500,000 gallons of water per ton of lithium. The brine then requires 12 to 18 months to evaporate. In addition to the environmental concerns related to lithium production, cobalt mining is unequivocally destructive on multiple levels. Concerning cobalt, graphite and nickel mining, studies have revealed human and environmental abuses ranging from child and slave labour, to toxic waste leakage and radioactivity [3].

Recycling: In truth, no one really knows if there is enough lithium for humanity's projected needs or where lithium can come from. It is now a contentious issue of how electric car is a solution to our non-renewable fuel crisis. Whereas lithium batteries are said to be 95 per cent recyclable, the practice of recycling them is more easily said than done. Throughout their lifespan, lithium batteries undergo irreversible damage as battery manufacturers incorporate several additives into the electrolyte liquid in the Li-ion battery. The purpose of these additives is to improve the battery in many ways, such as by speeding up the manufacturing process, or making the battery more durable in hot and cold weather. Recycled lithium is as much as five times the cost of lithium produced from the least costly brine-based process and is not pure enough to produce batteries, and the material ends up being used for non-battery purposes.

Emissions: Producing a midrange (84 miles per charge) BEV typically adds over one ton of emissions to the total manufacturing emissions, resulting in 15% greater emissions than in manufacturing a similar gasoline car. However, replacing gasoline use with electricity reduces overall emissions by 51% over the life of the car. Li-ion batteries are not a panacea to the world's energy problems amid climate catastrophes. The problems raised by Li-ion battery production might spur innovation that resolve these issues.

5. ALTERNATIVE FUELS FOR FUTURE

While conventional fuels will likely remain the standard heavy-duty transportation fuel for the near future, other forms of energy are slowly becoming more viable. Each one offers potential benefits and obstacles to overcome. These challenges must be scaled collectively by the transportation sector to proliferate the adoption of major diverse energy types like: Biodiesel, Natural Gas, Battery Electric and Hydrogen Fuel Cell.

A study by U.S. Department of Energy compares various transportation fuels like electricity, hydrogen, CNG, LNG, Ethanol and Carbon Jet fuels. The results reveal that the total transportation fuel use in BGGEs is highest for the electricity and next for hydrogen amongst all from the duration 2000–2050. [5]

Both shippers and carriers have a lot to consider as they aim to diversify their mix of transportation energy. It is a balancing act weighing many factors like Capital investment, Cost of energy consumption, available infrastructure, and sustainability goals.

6. HYDROGEN FUEL CELL

Hydrogen is the best or only choice for a scaled decarbonization of key segments like the gas grid, heavy transport and long distances. Fuel cells/ synfuels for: FCEV powertrains for trucks are cost competitive with BEV from 100 km range showed in fig.2. Hydrogen refuelling is 15 times faster than fast charging with a recharging time of just 10 minutes for 1000km range. Recharging infrastructure requires 10–15 times less space and creates flexible instead of peak load. [4]

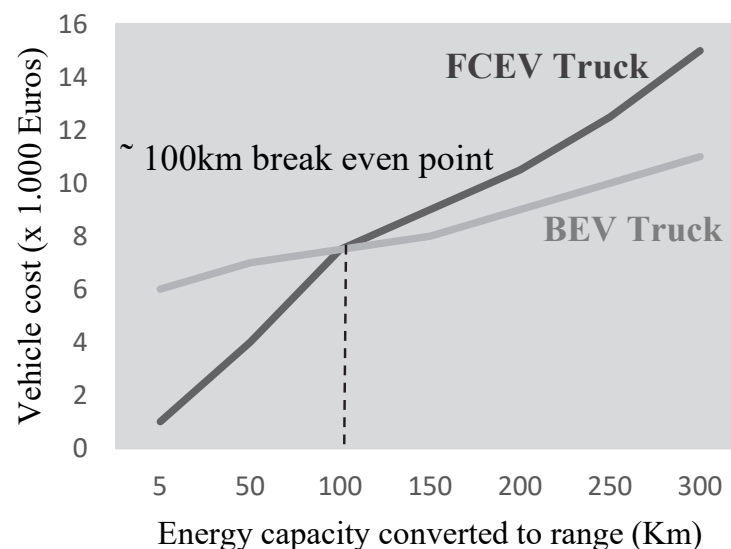


Fig. 18. Breakeven point indicating the range of fuel usage [4]

Conversion of hydrogen production to ultra-low carbon hydrogen Decarbonization of hydrogen production was currently used e.g., in ammonia production, refining and petrochemical industries and Ultra-low carbon H₂ as feedstock, e.g., Ammonia [4]

7. AMMONIA BASED FUEL CELLS

These fuel cells can be classified based on electrolyte, temperature, reactants, and ion-based transfer parameters. However, the five main types of direct ammonia fuel cells based on electrolyte type are as follows:

1. *Oxygen anion conducting electrolyte-based solid oxide fuel cells (SOFC-O)*
2. *Proton conducting electrolyte-based solid oxide fuel cells (SOFC-H)*
3. *Alkaline ammonia fuel cells (AAFCs) (including molten alkaline ammonia fuel cells)*
4. *Alkaline membrane-based fuel cells (AMFCs)*
5. *Microbial ammonia fuel cells.*

Presently, large-scale production of ammonia is typically carried out *via* the Haber-Bosch (H-B) process.[9][10]



A conventional H-B plant produces NH₃ by mixing nitrogen gas in the air and H₂ by LPG through steam reformation.[9] It is noticeable that even though NH₃ is carbon free, the production of it is not. Green ammonia can be obtained by carbon free renewable extraction methods like NRR (Nitrogen electrochemical Reduction Reaction) which may save up to 360 million tonnes of CO₂ emissions as designed by SIEMENS. [11][12]

The indirect use in hydrogen proton exchange membrane fuel cells (PEMFCs) would require the presence of a steam reformer in order to abstract hydrogen from the carbon source and a carbon capture and storage unit, which would contribute weight, additional space and cost. This has driven progress towards the use of nitrogen-based fuels like ammonia and hydrazine as carbon-free indirect hydrogen storage media. Ammonia contains 17.6% weight of hydrogen and, unlike ethanol and methanol, contains no carbon and therefore will not release CO₂ on decomposition.

Also, the relative cost is lower with a higher flammability, energy density than compressed and liquid hydrogen. [6][7]

Table 1. Comparison of various parameters between ammonia and hydrogen [6][7]

Fuel	Temperature [°C]	Pressure [MPa]	Weight [% H ₂]	Energy density [MJ L ⁻¹]	Flammability range	Relative cost
Compressed hydrogen	25	35	100	2.76	4–74	HIGH
Liquid hydrogen	-235	0.1	100	8.6	4–74	HIGH
Liquid ammonia	25	1	17.6	12.9	16–25	LOW

7.1 ADVANTAGES AND DISADVANTAGES OF FUEL CELLS

Hydrogen stands to be the most efficient solution apart from batteries with an 80% energy efficiency, good reliability, quality power, no degradation and smooth noiseless driving experience in a compact vehicle. Meanwhile H₂ comes with an expensive manufacturing due the high cost of catalysts (platinum) and lack of infrastructure to support the distribution of hydrogen as it is all in the prototyping stage.[14]

NH₃ is easier to be transported compared to hydrogen. It costs less to produce, store, and deliver as compressed and/or cryogenic hydrogen. The infrastructure for NH₃ already exists while for hydrogen, new fuelling stations must be built, which is a big investment.[15]

A lower energy density compared to hydrogen-based fuels and toxicity are the two major disadvantages with ammonia. The calorific value of ammonia is 22.5 MJ/kg (9690 BTU/lb), which is about half that of diesel. In a normal engine the calorific value of ammonia will be about 21% less than this value.[8] However, the global nitrogen cycle could eventually get affected with the large-scale use of NH₃, which may lead to serious nitrogen crisis in place of our current environmental problems.

8. CONCLUSION

With this study, one can conclude that the growing trends in the adoption of EVs, the batteries which are crucial in cost defining and reliability of EVs are in cardinal focus. The impact of Lithium-ion batteries has been significant in the adoption of EVs and its upgradation to newer variants of batteries like Solid-state Batteries serve in cutting down the emissions even more. However, the availability of Lithium mines, extraction, and impact of its production on environment are of concern. Alternate means like Hydrogen and ammonia fuel cells could be sources of clean fuels to drive vehicles. This study would suggest that light motor vehicles and public transportation would adopt battery powered fuel meanwhile, the high end heavy-duty transportation intend to utilise fuel cell-based energy for its traction and to mitigate sole dependency on batteries.

The battery-powered electric vehicle is better positioned with regard to emissions and have different performances in terms of range and fuelling methods, but a comparison needs to take the long term environmental impacts over-all and not just the net CO₂ capture into consideration. A complementary analysis would be necessary on a system-wide scale, depending on the nature of the electricity used for fuelling. As the renewable electricity, is variable over time, and recharging the battery-electric vehicle by this source might possibly require additional stationary storage of the electricity. On the other hand, large infrastructure and an efficient energy supply management is needed for all impending fuel alternatives discussed in this paper.

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Key words:
packed bed, rotating packed beds (RPBs), packings, extraction, absorption

Adrian STRAUB¹

ADVANCES AND INNOVATIONS IN THE FIELD OF PACKED BEDS USED FOR EXTRACTION AND ABSORPTION

Thermal separation processes like distillation and absorption are one of the most important basic operations of process engineering. Over the last decades advances have been made to improve those highly energy intensive operations. This is achieved by changing geometry and material of the used packing. For random packings, the simple cylindric form has changed to more complex and open shapes. Structured packings are varied in their corrugation angle and have an increased void fraction/porosity. The improvement is evaluated by decrease in pressure drop and HETP. A promising alternative to the common columns are rotating packed bed (RPB) reactors. This technology does not rely on gravity to cause the counter flow between the two reacting phases, but on centrifugal force. RPB units offer comparable results but at a much lower plant size. Research in this field is improved by advances in computational simulations and additive manufacturing.

1. INTRODUCTION

The separation of single-phase or multi-phase fluid mixtures is one of the most important basic operations in modern process engineering [1]. It is the foundation for the refining and purification of bulk chemicals, which are used as a base for all products. In petrochemistry, for example, a variety of liquid fuels is produced from crude oil with the help of separation processes as shown in Fig. 6. The thermal separation processes (mainly distillation/rectification and absorption) are highly energy intensive. Their energy consumption amounts to approximately 3 % of the global energy consumption. In light of climate change and the drive to cost reduction, old methods are improved and new ones developed.

Especially in distillation and absorption, the focus is on the interactions of the gas and liquid phases. In the past, special random packings were developed to increase the phase interface and thus improve the turnover. Structured packings have also been used to increase the interface and reduce the pressure drop. Especially when using steam, the amount of steam needed can be reduced by minimising the pressure loss and thereby save costs.

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The aim of this paper is to give an overview of the advances and innovations in the field of packed beds.

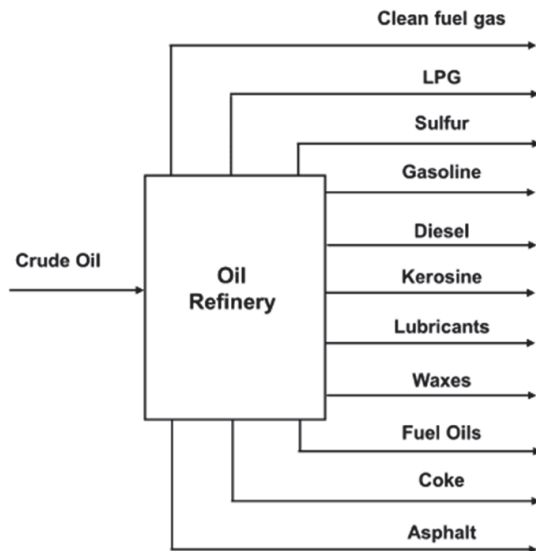


Fig. 6. Very simple schematic of a refinery for converting crude oil into products. [1]

2. FUNDAMENTALS

2.1. PACKED BED COLUMNS

Packed bed columns are generally used for distillation and absorption of gas/liquid systems. Normally, configured as counterflow, the liquid phase enters the column at the head, whilst the gas phase is brought in through the column sump. The packed beds sit in between and consist either of random packings or of structured packings as shown in Fig. 7. The liquid phase is distributed evenly over the packing via the liquid distributor so that the packing is completely wetted. The liquid then flows along the angled structures of the packing, increasing the surface area of the liquid phase. In the packed bed, the liquid comes into contact with the gas stream flowing in from below. Depending on the packing structure and design, the specific surface area, which is decisive for the phase interface, changes, as do pressure loss and operating range.

In order to compare different packed beds we need to define the critical parameters and their influence.

The amount of liquid being used is described by the specific liquid load based on cross-sectional area of an empty column $u_L \left[\frac{m^3}{m^2 \cdot s} \right]$. The gas load is given in form of the F-factor. It connects the gas velocity u_G with the density of the liquid phase.

$$F = u_G \cdot \sqrt{\rho} \quad (1)$$

The pressure drop Δp in a packing column is made up of several components. In addition to the pressure loss caused by the column and its internals, such as the liquid distributor, it is the pressure drop of the packing that is of particular importance. It is generally given in relation to the height of the packing. It also needs to be distinguished between the dry and wet state. The dry pressure loss depends solely on the gas load and the geometry of the packing. However, if the packing is irrigated, the liquid reduces the freely available flow cross-section in the packing, which leads to an increase of the gas velocity in the channels. [2]

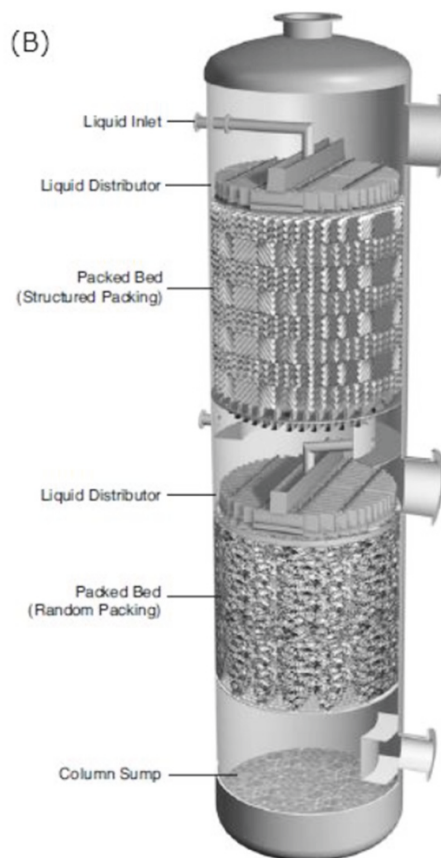


Fig. 7 Schematics of a packed column [2]

2.2. IMPORTANT PARAMETERS

To give an information about the mass transfer and by that over the efficiency of the column the HETP (height equivalent of a theoretical plate) is measured. A lower HETP/HETS signifies more theoretical plates fit into the length of the column and thus

a better efficiency. An additional key parameter is the liquid holdup. It is highly related to the liquid pressure drop, as well as the phase exchange process. It describes the volume of liquid in the void space of the packing. [3]

3. NEW PACKING GEOMETRIES

3.1. METHODS OF EVALUATION

To investigate the new designed packings two approaches are generally used. The first one is a theoretical evaluation via numerical simulations in a Computational Fluid Dynamics (CFD) program. The other method used is called rapid prototyping. The packing is modelled in CAD software and afterwards 3D-printed. A test bench is then be used to collect real life data. Advances in both, fluid simulations and additive manufacturing, are improving the accuracy and accessibility of those methods.

3.2. EXAMPLES

Over time, new geometries have been developed and improved. Random packings started from simple cylinders like the Raschig ring (1915) and changed to complex shapes like the current Raschig Super-Ring PLUS (Fig. 8).

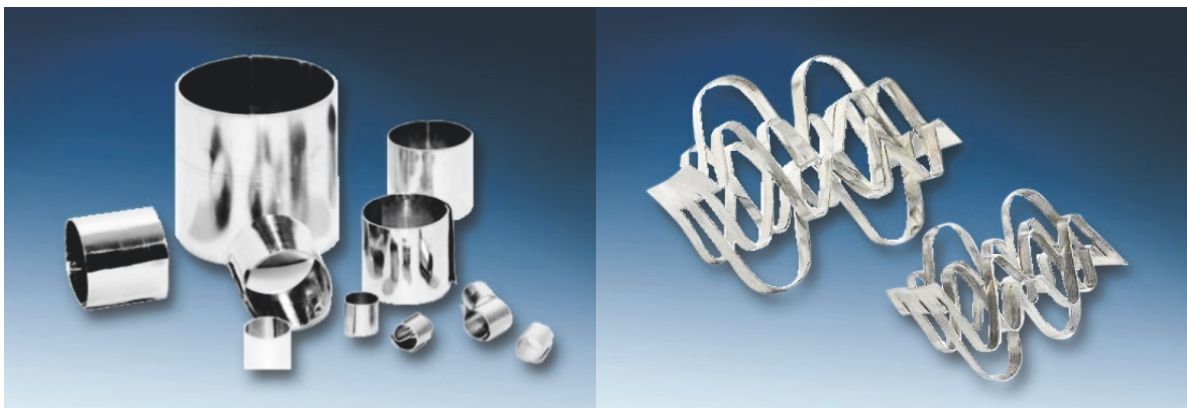


Fig. 8. Random packing left 'Raschig ring', right 'Raschig Super-Ring PLUS' [4]

Fehler! Ungültiger Eigenverweis auf Textmarke. shows the huge improvement achieved within one generation of development. By having a more open geometry the pressure drop is decreased by up to 60 %. In addition to that a higher efficiency is reached, shown in the reduction of the HETP. Another advantage of these new geometries is the higher resistance against fouling occurring for example in Toluene-di-isocyanate (TDI) process [5].

Looking at structured packings also improvements have been made over the years. Starting out in the early 1940s with simple wire mesh or metal sheets they were developed into specially corrugated metal sheets with modified surfaces to improve

wettability and thus performance [6]. To give an overview Fig. 10 shows the different generations of structured packings over the years. Besides the traditional folded/corrugated metal sheets, new geometries are being developed and tested. The key parameters being changed are the corrugation angle and the void fraction. To change the void fraction or porosity different materials are used. Fig. 9 shows a packing made from Silicon Carbide (SiC). Higher porosity means a better mass transfer/ smaller HETP, although with to bigger pores the residence time is decreased due to the reduction of capillary forces. [7]

Table 9 Performance comparison between second and third generation metal packing for an ammonia-air/water system at 1 bar [5]

Existing Packing	Revamped Packing	At same throughput	
		Press. drop	HETP
Pall Ring 5/8"	Raschig Super-Ring No. 0.3	- 40%	- 18%
Pall-Ring 1"	Raschig Super-Ring No. 0.5	- 21%	- 23%
Pall Ring 1"	Raschig Super-Ring No. 0.7	- 53%	- 14%
Pall Ring 1.5 "	Raschig Super-Ring No. 1	- 33%	- 24%
Pall Ring 1.5 "	Raschig Super-Ring No. 1.5	- 57%	- 11%
Pall Ring 2"	Raschig Super-Ring No. 2	- 58 %	- 11 %
Pall Ring 3"	Raschig Super-Ring No. 3	- 60%	- 7%

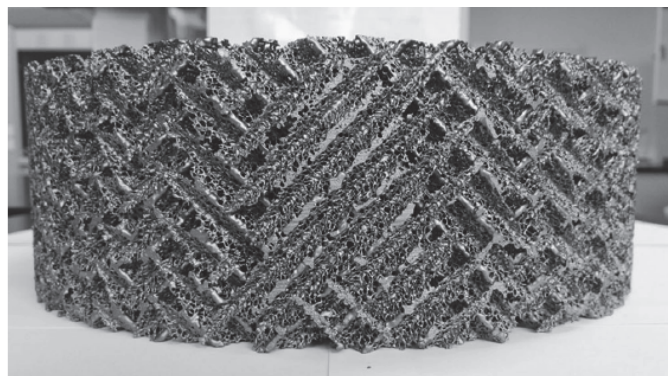


Fig. 9. Structured packing made from SiC, model CFP-500Y-D5 [7]

The influence of the corrugation angle was studied and compared to common packings [8, 9]. In general, it has been found that the pressure drop is significantly lower at a steeper angle, this is a result of the milder change in flow direction the gas phase encounters. A steeper inclination angle was researched for CO₂ capture. By increasing

the angle from 45° to 75° the pressure drop is reduced by over 90° while the separation efficiency is only slightly decreased [8].

In the optimization of CO_2 capture not only new packings are used but also new alternative technologies improved. Those processes shall be discussed in the following.

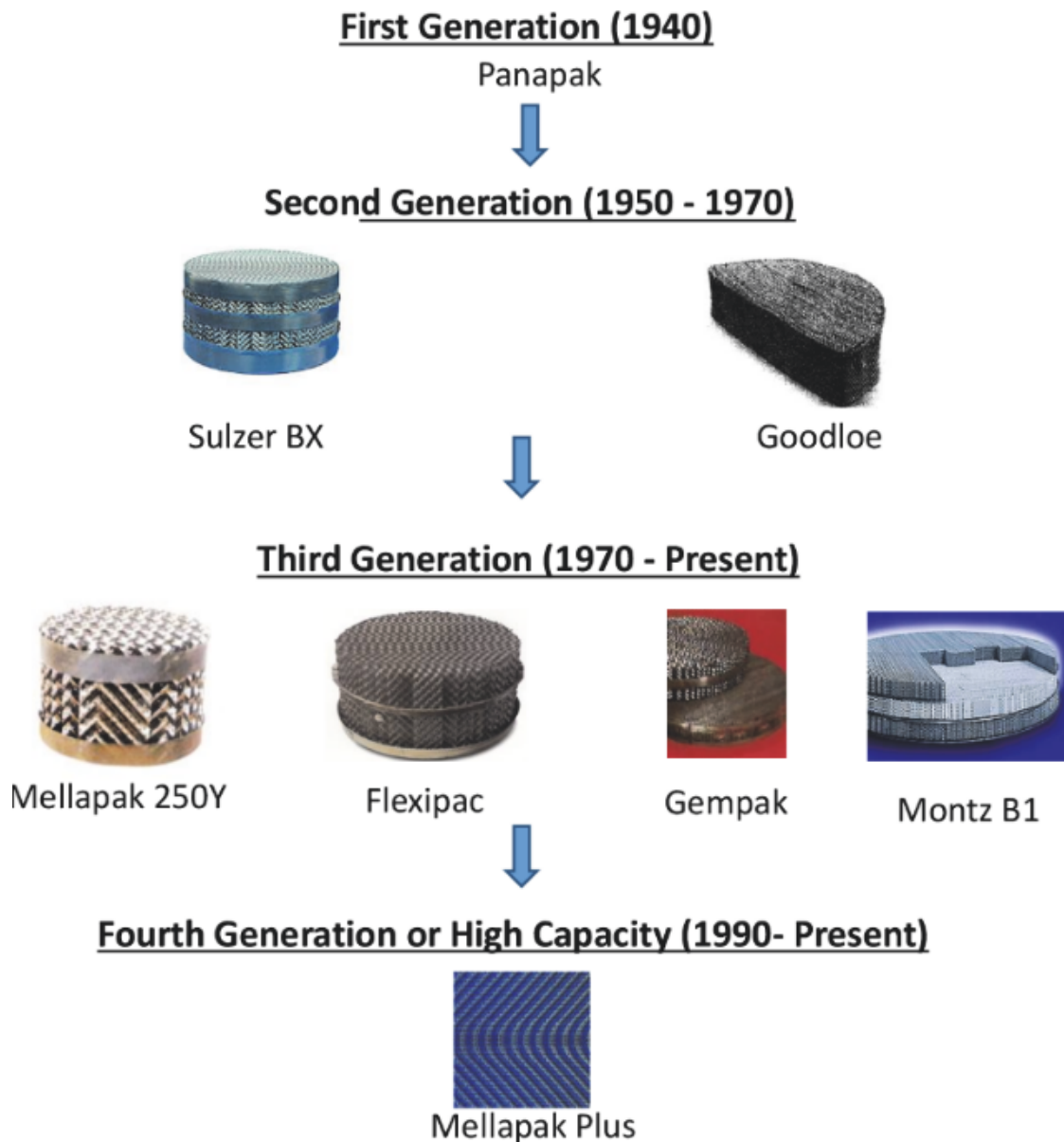


Fig. 10. Different generations of structured packings [10]

4. NEW TECHNOLOGIES AND APPLICATIONS

4.1. ROTATING PACKED BEDS

In the before mentioned columns the gravitational force is used to produce a counterflow between the two phases. A different approach is the use of centrifugal forces. Those are achieved by rotating the inner part of the reactor which contains the packings. Fig. 11 shows the liquid phase getting distributed in the rotating packed bed (RPB), where it is pushed through and comes into contact with the gas phase. Those RPB-reactors are also known as HiGee, meaning high G-force, as they reach a centrifugal field 100-1000 greater than the earths gravitation [11].

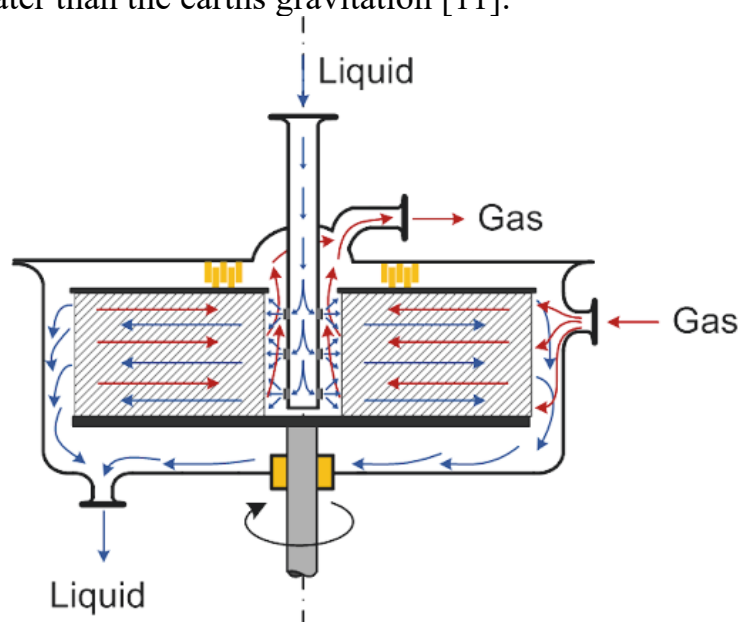


Fig. 11. schematic of a rotating packed bed reactor [12]

One of the biggest advantages of RPBs is the reduction in size compared to traditional columns. This is owed to the thinner liquid films, which benefit mass and heat transfer and lead to a reduction in size up to 10 times [13]. Another advantage besides the lower material cost, is the lower liquid hold-up, which makes RPBs inherently safer in the use of dangerous substances [14]. Disadvantages to the standard column are the increased pressure drop as well as the moving parts leading to higher maintenance requirement. The latter is partially compensated by the short start-up and shutdown times of RPBs.

One of the popular applications of RPBs is in the capture of CO₂. Due to their compact design RPBs are suited for processes where space is limited, which makes them a promising technology for offshore-use on oil and gas rigs [15]. In cases of thermal

regeneration of a CO₂ contaminated solution a RPB unit proved to have a lower energy consumption, than a regular distillation process [16].

5. CONCLUSION

Through the technology of computational simulations and rapid prototyping there has been a lot of advances in the field of packed beds for distillation and absorption in the last decade. For Random packings the shapes have shifted from simple cylinders to complex hollow shapes. For structured packings changes have been made in the choice of materials with the experimental use of more porous substances like SiC. In addition to that new angles and layerings are researched, all with the goal to improve efficiency and reduce energy consumption. This drive has resulted in a higher interest in less common technologies like RPB reactors. This centrifugal based process achieves comparable results in some applications at a much lower plant size.

The optimization in the field of packed beds has yet to reach its final form and will play an important role in battling climate change.

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