

Proceedings of Global Conference on Decarbonizing India

EDITOR(s) IN CHIEF

Dr T Prabu

Dr K Mayilsamy

Dr P Karthikeyan

Dr P Viswanathan

Dr S Babu



Sponsors



Barani Hydraulics

PSG & Sons' Charities

PSG & Sons' Charities Trust has been rendering yeoman service to the community by taking up the noble cause of education and training.

The profound vision of Shri. P.S. Govindaswamy Naidu conceived over 92 years ago to take up this cause has resulted in the education of over 3,00,000 students, mostly drawn from economically weaker sections of the society. This phenomenal success has come from the noble act of the four brothers of the PSG family, who went on to create a fifth brother, i.e., Charity.

The Trust is one of the oldest charitable organizations in India dedicated to empowerment and social change through education in Liberal Arts, Management and Science and Technology. It is rooted in the Gandhian principles to establish a classless society. The Trust runs several educational Institutions from Kindergarten to Doctoral levels and the Institutions are reputed for their academic excellence. The Trust continues to strive for imparting quality education and boasts of its illustrious alumni located all over the world.



P.S. GOVINDASWAMY NAIDU
PSG & Sons' Charities Trust

"Let there be charity,
so that other people can
share my family's prosperity"

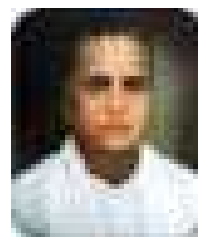
Founders



PSG Venkataswamy Naidu



PSG Rangaswamy Naidu



PSG Ganga Naidu



PSG Narayanaswamy Naidu



PSG College of Technology, Coimbatore - 641004
Department of Mechanical Engineering

**Global Conference
on
Decarbonizing India**

GCDI - 2023

December 15 - 16



This journal and the individual contributions contained in it are protected under the copyright by GCDI 2023 and the following terms and conditions apply to their use:

Photocopying

Single photocopies of single articles may be made for personal use as allowed by national copyright laws. Permission of the Publisher and payment of a fee is required for all other photocopying, including multiple or systematic copying, copying for advertising or promotional purposes, resale, and all forms of document delivery. Special rates are available for educational institutions that wish to make photocopies for non-profit educational classroom use.

For information visit <https://psgtech.edu/gcdi2023/>

Derivative Works

Subscribers may reproduce tables of contents or prepare lists of articles including abstracts for internal circulation within their institutions. Permission of the Publisher is required for resale or distribution outside the institution. Permission of the Publisher is required for all other derivative works, including compilations and translations (“permission website”)

Electronic Storage or Usage

Permission of the Publisher is required to store or use electronically any material contained in this journal, including any article or part of an article (please consult “permission website”)

Except as outlined above, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without prior written permission of the Publisher.

Notice

No responsibility is assumed by the Publisher for any injury and /or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. Because of rapid advances in the medical sciences, in particular, independent verification of diagnoses and drug dosages should be made.

Although all advertising material is expected to conform to ethical (medical) standards, inclusion in this publication does not constitute a guarantee or endorsement of the quality or value of such product or of the claims made of it by its manufacturer.

ISBN 978-93-95105-33-0

Contents

Messages

Message from Chief Patron
Message from Patron
Message from Conference Chair
Message from Conference Academic Chair
Message from Conference Industrial Chair
Message from Conference Advisor
Message from Conference Co-Chair
Message from Conference Co-Chair
Message from Conference Co-Chair
Message from Organizing Secretaries

About GCDI

Committees

Advisory Committees
Organizing Committees

Speakers

Programme Schedule

Keynote Speakers

Mrs Disha Agarwal
Winds of change for India's power sector transition

Dr Karunamoorthy
Sustainable Integration For Future Business Development

Dr K S Reddy
Energy Storage System for Improvement of Reliability of CSP Plants

Mr A D Thirumoorthy
Role of Solar Energy in Decarbonization

Mr Nishant Attri
Carbon Capture Utilization and Storage and Green Hydrogen

Dr Senthilarasu Sundaram
Materials innovation for Perovskite solar cells efficiency and lifetime increase

Mr David Jayanth Issac
Decarbonization Pathways for the Cement Industry

Mr Mariasundaram Antony
Driving Energy Transition across the Energy Value Chain

Dr Anil Misra
The Role of Renewable Energy in Sustainable Development

Mr Rahul Wagh
Addressing Energy Transition through Technology Leadership

Mr Umang Swaroop
Heat Pump

Mr Selvaraji Muthu

MAHLE Advanced Products technologies for Carbon-neutral Powertrains and New Energy Vehicles

Dr Sushil S Ramdasi

Challenges and Opportunities in Indigenization of E Mobility from an Indian Prespectives

Mr Vipindas Othiyil, Dr Balaji Srinivasan

Hydrogen based technology for stationary applications - SOFC

Mr Gaurav Kumar

Compressed Air Energy Storage

Mr Sayantan Paul

Carbon Capture Utilization and Storage and Green Hydrogen

Dr R Sethumadhavan

Decarbonization in Industries thro' Adoption of Energy Efficiency & Renewable Power

Mr K N Jayashankar

Technology advancement in Wind turbine and Market need

Dr Keerthivasan Rajamani

CO2 capture - Overview and insight

Manuscripts - GCDI 2023

- 23106 - Scenario of Solar Photovoltaic Water Pumping
- 23110 - Small and Domestic Ammonia Cooling Systems for Energy and Sustainability of India
- 23112 - Effect of cross-sectional geometry in flow behaviour: A steady state computational study
- 23114 - Effect of Manifold and Distributor Dimensions of Flow characteristics in PEM Fuel Cell Stack
- 23116 - Standardization of fermentation conditions for the production of bio-ethanol from matured coconut water
- 23117 - Co-pyrolysis of Plastic Waste and Lignocellulosic Biomass for High-Recovery Fuel Oil
- 23120 - A Novel Battery Charging Method for Plug-in Fuel Cell Hybrid Electric Vehicle
- 23122 - Carbon Capture and Storage Potential in India
- 23138 - Investigation of different origin fried oils and its biodiesel using Gas Chromatography – FID Chromatogram
- 23143 - Identification of Optimum Location and Designing of Sustainable Charging station for the electric vehicles
- 23153 - Configuring pilot Gas Generator with Green propulsion systems

Abstracts - GCDI 2023

- 23101 - Energy Recovery Devices for Desalination
- 23102 - Revolutionizing Maritime Transport: A Blueprint for Sustainable Mobility - Conceptualizing an Electric Roll-On/Roll-Off (RO-RO) Ferry System for India's National Waterway 3
- 23103 - Decarbonising India through Sustainable Consumption – An Analysis of Customer Awareness, Availability and Adoption of Panchagavya Products
- 23104 - CO2 Dehydration for CCUS
- 23105 - Study on Consumer Behaviour on Refashioning Hand-Me-Down Sarees as an Advancing Circular Fashion Practice
- 23108 - Development of Innovative Forming Process for Automotive Body Parts to Reduce mission and Energy Consumption

- 23109 - Designing and Experimental Analysis Of Dye Sensitized Solar Cell Using Titanium Dioxide and Natural Dye
- 23111 - Proton Exchange Membrane Fuel Cell: A Computational Study of Bi-Polar Plate (BPP) Design Concepts
- 23113 - An experimental study on variable speed fan cooling for hydrogen fuel cell application
- 23115 - Electric Vehicle Battery Pack Cooling Using Predictive Control Strategy Under Different Driving Conditions
- 23118 - Removal of Fermentation Inhibitor to Maximize the Bioethanol Production
- 23119 - Development of Evacuated Tube Solar Air Heating System for Drying Grapes
- 23121 - Recent Trends on Climate Impact of Plastics and Exploring Sustainable Alternative for a Greener Future
- 23123 - Metropolitan Strategies of Advancing Decarbonization Across India
- 23124 - Green Technology Minimizing Carbon Footprint for Lubricants
- 23125 - Green Technology Initiatives and Government Policies: Driving ESG Compliance and Carbon Reduction in India
- 23126 - Innovation and Eco Design for Sustainability
- 23127 - A Review on Significance of the Circular Economy in Addressing Climate Change: A Perspective Using the Theory of Change Methodology
- 23128 - Climatic Impact On Thermal Power Plant
- 23134 - Grid To Vehicle and Vehicle To Grid Bidirectional AC-DC Converter and DC-DC Converter
- 23135 - Climatic Impact On Thermal Power Plant
- 23136 - Climate vulnerability and its impact on financial markets
- 23137 - Managing the Convergence: How Industry 4.0 can augment India's Decarbonization Vision
- 23139 - Air Gap Analysis and Optimization for 2.8MW Permanent Magnet Synchronous Generator
- 23140 - GIS - Based Impact Studies on The Proposed Metro Rail corridor - Coimbatore city and Local Planning Area (LPA)
- 23141 - Syntropic Agroforestry: A Sustainable Solution for Carbon Emission Reduction in India
- 23142 - A study on power generation carbon footprint change in the state of Tamilnadu using solar PV and PVT technologies
- 23144 - A roadmap for India towards decarbonization
- 23146 - Advances in Waste to the Energy System for Decarbonisation in Coimbatore
- 23147 - Offshore Wind Generators
- 23148 - Modification of Small Wind Turbine Airfoil for Sustainable Power Generation
- 23149 - IOT based Waste Management System for Smart City
- 23151 - Evaluation of Energy Conservation Opportunities in Gloves Industry
- 23152 - Rethinking Network Distribution Charges Design in the context of increasing active consumers in the Indian Electricity Market
- 23154 - Design and Analysis of a Proposed Energy Harvester for Turbine Vent Using Piezoelectric and Tribo- Electric Nano-Generators
- 23155 - Analyzing Two Wheeler Aftermarket Parts Based on Perspective of Two Wheeler Technicians
- 23156 - Impact of Quantum Locking in Sustainable Manufacturing Practices

Message from Chief Patron



Shri L Gopalakrishnan

Managing Trustee,
PSG Institutions

I applaud the Department of Mechanical Engineering and the organizers for hosting the Global Conference on “Decarbonizing India” during December 15-16, 2023, at PSG College of Technology in Coimbatore. I am genuinely delighted to extend a warm welcome to attendees of this conference, who come from across the nation and around the globe.

I am sure that academicians, researchers, business representatives, and other attendees shall contribute, enjoy and cherish the conference proceedings, leaving a lasting legacy for PSG College of Technology. I want to express my gratitude to everyone for their dedication and enthusiastic involvement, and I wish them the best of luck.

Shri L Gopalakrishnan

Managing Trustee,
PSG Institutions

Message from Patron



Dr K Prakasan

Principal,
PSG College of Technology

Department of Mechanical Engineering is organising the Global Conference on “Decarbonizing India” during December 15-16, 2023, collaborating with industry and academia. The series of events that took place at National and International Forums towards mitigating the levels of global warming and these Conferences highlight the importance of the theme and relevance for sustained growth of industry. The discussions will be of great significance and lead to implementation of a few major recommendations that are in resonance with the findings at global level of research to make earth cooler and greener.

I express my happiness towards the conduct of this conference and congratulate the team who envisaged the theme that addresses SDGs and worked towards their realization.

Dr K Prakasan

Principal,
PSG College of Technology

Message from Conference Chair



Dr R Rudramoorthy

Director,
PSGCARE

In order to advance research and development in the areas of green evolution and decarbonizing India, this conference offers a forum for business, academics, and students to network and share ideas. One of the conferences that receives the most referrals is the Global Conference on “Decarbonizing India”. The goal of GCDI is to facilitate effective social networking among scholars working on green evolution and decarbonizing India, showcasing their contributions to society. I commend everyone involved in the conference for planning it and publishing the proceedings. I would want to take this opportunity to congratulate the department's staff and students for their hard work and initiative, and I hope the conference is a sensation.

Dr R Rudramoorthy

Director,
PSGCARE

Message from Conference Academic Chair



Dr P R Thyla
Professor and Head,
Department of
Mechanical Engineering,
PSG College of Technology

It gives me great pleasure to welcome you to the Global Conference on “Decarbonizing India” presented by the Department of Mechanical Engineering at PSG College of Technology during December 15-16, 2023. I'm hoping that this conference will give academics, business leaders, and students a great chance to expand their understanding of cutting-edge technology in the rapidly developing fields of green evolution and decarbonizing India. I congratulate the conference's organizing secretaries for their tireless efforts and appreciate the collaboration of all the faculty members. My best wishes for successful conduct of the conference.

Dr P R Thyla
Professor and Head,
Department of
Mechanical Engineering,
PSG College of Technology

Message from Conference Industrial Chair



Dr K Kasthurirangaian
Chairman, Indian Wind Power
Association

I thank the department of mechanical engineering and the organizers for conducting the Global Conference on “Decarbonizing India” at PSG College of Technology in Coimbatore on December 15-16, 2023. It gives me great pleasure to greet the people from all around the country who have come to this meeting.

The conference proceedings will surely lead to enhanced knowledge, besides being valued and enjoyed by academicians, researchers, business leaders, and other guests, leaving a lasting legacy for PSG College of Technology. I express my sincere gratitude to everyone for their hard work and fervent participation and wish them luck.

Dr K Kasthurirangaian
Chairman, Indian Wind Power
Association

Message from Conference Advisor



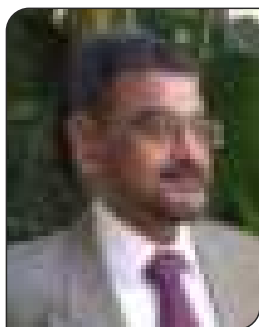
Dr V Narayanan
Distinguished Scientist &
Director, ISRO

It is with great pleasure and gratitude that I accept your kind invitation to be a part of the Global Conference on “Decarbonizing India”. As a representative of ISRO, I am honored to contribute insights into our nation's endeavors in fostering sustainable practices and decarbonization strategies.

This conference provides a crucial platform to share experiences, collaborate with industry experts, and collectively explore innovative solutions to address the challenges of decarbonization. I look forward to engaging in meaningful discussions that can pave the way for a more sustainable and environmentally conscious future.

Dr V Narayanan
Distinguished Scientist &
Director, ISRO

Message from Conference Co-Chair



Dr G (Subbu) Subbaraman

Distinguished Scientist &
Director, ISRO

This conference provides an opportunity for business, academia, and students to network and exchange ideas in order to enhance research and development in the fields of green evolution and decarbonizing India. The Global Conference on “Decarbonizing India” is one of the most recommended conferences. In order to highlight the contributions that academics working on green evolution and decarbonizing India have to society, GCDI aims to effectively facilitate social networking amongst these scholars. I want to express my gratitude to the organizing secretaries of the conference for their incredibly hard work and the cooperation of all the faculty members. You have my best wishes for an amazing conference.

Dr G (Subbu) Subbaraman

Distinguished Scientist &
Director, ISRO

Message from Conference Co-Chair



Dr Jayanta Kapat

Professor,
University of Central Florida, USA

It is with great pleasure that the Global Conference on “Decarbonizing India” will take place at PSG College of Technology's Mechanical Engineering Department in Coimbatore. Academicians, researchers, business executives, and other attendees will undoubtedly improve, value, and enjoy the conference proceedings, leaving a lasting legacy for PSG College of Technology. I am grateful to everyone for their diligent work and enthusiastic participation and wish them great success.

Dr Jayanta Kapat

Professor,
University of Central Florida, USA

Message from Conference Co-Chair



Dr S Sankaran

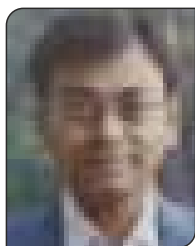
Chief General Manager,
Indian Space Research Organization

I take immense pleasure in appreciating the Mechanical Engineering Department and the Organizers and PSG Tech apex Management for bringing the Global International Conference on “Decarbonizing India” to PSG College of Technology in Coimbatore on December 15-16, 2023. I am very much pleased to know that many stalwarts both from abroad and from India are participating in this august conference delivering valuable talk in their area of expertise. ISSE being one of the nodal agencies which is supporting this conference, which connects the academia and industries. I am sure that all the participants would enjoy the proceedings of this conference and GCDI seeks to effectively facilitate social networking among all the scholars and entrepreneurs & students, working on green evolution and decarbonizing India. Wishing a very fruitful conference.

Dr S Sankaran

Chief General Manager,
Indian Space Research Organization

Message from Organizing Secretaries



Dr T Prabu

Professor,
Dept. of Mechanical Engg.,
PSG College of Technology



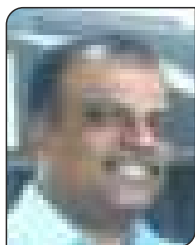
Dr K Mayilsamy

Professor,
Dept. of Mechanical Engg.,
PSG College of Technology



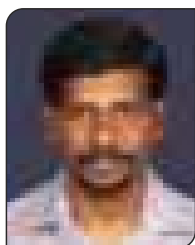
Dr P Karthikeyan

Professor,
Dept. of Automobile Engg.,
PSG College of Technology



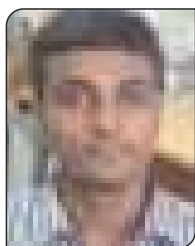
Dr P Viswanathan

Associate Professor,
Dept. of Mechanical Engg.,
PSG College of Technology



Dr S Babu

Associate Professor,
Dept. of Mechanical Engg.,
PSG College of Technology



Dr R Arun Kumar

Assistant Professor(Sr.Gr.),
Dept. of Mechanical Engg.,
PSG College of Technology

We're excited to announce the Global Conference on “Decarbonizing India” at PSG College of Technology, Coimbatore - a crucial event in the ongoing series addressing carbon emission challenges. GCDI-2023 provides a collaborative platform for experts, policymakers, industry leaders, researchers, and academics to discuss innovative solutions for sustainable development.

Recognizing the critical need for strategic planning, the conference addresses India's annual emission of 2.9 GtCO₂e, contributing 4.9% to global emissions, and a per capita emission of 1.8 tons CO₂e. Sectors like power, automotive, aviation, steel, cement, and agriculture underscore the urgency for impactful interventions in our growing economy.

Anticipating dynamic discussions, the conference covers topics such as renewable energy, energy efficiency, clean transportation, sustainable urban planning, circular economy practices, climate finance, and international collaborations. Aimed at achieving decarbonization, the event explores how technology developments can propel India towards its net-zero-by-2070 commitment.

Book by a Conference Advisor



Dr Vikram Rao

Executive Director,
Research Triangle Energy Consortium,
Durham, North Carolina, USA

Carbon-free power

Abstract

There is a new world order in electrical energy production. Solar and wind power are established as the low-cost leaders. However, these energy sources are highly variable and electrical power is needed 24/7. Alternative sources must fill the gaps, but only a few are both economical and carbon-free or -neutral.

This book presents one alternative: small modular nuclear reactors (SMRs). The authors describe the technology, including its safety and economic aspects, and assess its fit with other carbon-free energy sources, storage solutions, and industrial opportunities. They also explain the challenges with SMRs, including public acceptance.

The purpose of the book is to help readers consider these relatively new reactors as part of an appropriate energy mix for the future and, ultimately, to make their own judgments on the merits of the arguments for SMRs.

Link:

<https://www.rti.org/rti-press-publication/carbon-free-power>



INAUGURAL SESSION

December 15, 2023

Time Slot	Programme	Speakers
09.30 - 09.33	Invocation - Tamil Thai Vazhthu	Student Volunteer
09.33 - 09.36	Welcome Address	Dr P R Thyla, HoD-Mechanical, PSG College of Technology.
09.36 - 09.38	About the Conference	Dr T Prabu, Organizing Secretary, GCDI'23.
09.38 - 09.43	Presidential Address	Dr K Prakasan, Principal, PSG College of Technology.
09.43 - 09.53	Guest of Honour	Mr K Veerabathraswamy, CMI Manager, Cameron, a Schlumberger Company.
09.53 - 10.03	Guest of Honour	Dr A V Varadharajan, Chairman, AV Group of Companies.
10.03 - 10.10	Felicitation Address by	Dr R Rudramoorthy, Director, PSG CARE.
10.10 - 10.20		Dr K Kasthurirangaian, Chairman, Indian Wind Power Association.
10.20 - 10.30		Dr Ganesan Subbaraman, Institute Fellow, GTI, USA.
10.30 - 10.40		Dr Jayanta Kapat, Prof. & CATER Director, UCF, USA.
10.40 - 11.00	Chief Guest Address	Dr V Narayanan, Director, LPSC, ISRO.
11.00 - 11.10	GCDI-2023 Proceedings Release by	Shri L Gopalakrishnan, Managing Trustee, PSG Institutions.
11.10 - 11.15	Vote of Thanks	Dr P Viswanathan, Organizing Secretary, GCDI'23.
11.15 - 11.30	High Tea	

About GCDI

Global Conference on “Decarbonizing India”

December 15-16, 2023

The Global Conference on Decarbonizing India 2023 stands as a pivotal international event dedicated to tackling the pressing challenges associated with carbon emissions in India. With the nation currently emitting 2.9 GtCO₂e annually, making up 4.9% of global emissions, and a per capita emission of 1.8 tons CO₂e, there is a critical need for strategic planning amidst the country's burgeoning economy. Key sectors such as power, automotive, aviation, steel, cement, and agriculture contribute significantly, comprising approximately 70% of India's total emissions. As per 2022 McKinsey report, a substantial portion of the industry expected in the India of 2050 and beyond is yet to be constructed, necessitating prompt policy interventions to shape low-carbon capacities.

The conference serves as a unique platform that brings together a diverse array of stakeholders, including experts, policymakers, industry leaders, researchers, and academics, all united by a common goal of fostering sustainable practices and clean energy technologies. Addressing the need for an estimated US\$7.2 trillion in green investments until 2050 to achieve decarbonization, the conference aims to facilitate discussions on renewable energy deployment, energy efficiency measures, clean transportation solutions, sustainable urban planning, circular economy practices, climate finance, policy frameworks, and international collaborations.

Indian Wind Power Association

Committed to achieving India's climate change goals through maximising use of its wind potential



IWPA

helping mankind with energy from nature

About IWPA

A not-for-profit all-India Association focused on creating an enabling regulatory and policy environment, conducive to investment in the wind industry.

In service of the wind industry for the last 27 years

Its members collectively own around 25,000 MW of the installed wind energy capacity in the country

Actively supports the national goals of energy access at affordable prices, economic development of India's manufacturing capacity, energy security and independence, and meeting the goals of greater sustainability

Operates in all the windy states of India



Benefits of membership

- A Forum to offer comments / suggestions that steer policy formulation.
- Views taken cognizance of at appropriate forums and factored in policy decisions.
- Protection of stakeholder interests through representations and follow up with Regulatory / Government bodies.
- Protective platform to take up legally contentious issues at affordable cost.
- Conferences and Workshops which help members keep in step with the latest trends and developments.
- Dissemination of relevant information.
- Opportunities for networking.

Benefits delivered

- Contributed to streamlining the bidding guidelines for RE Projects.
- De-bottlenecking project execution.
- Setting the landscape for year-long Banking of wind energy and providing pointers for a National-level policy on the same.
- Introducing wind energy forecasting in Tamil Nadu, resulting in an 85% increase in evacuation.
- Reducing the financial burden involved in setting up wind energy forecasting in Tamil Nadu by suggesting the use of AMR data in place of RTUs.
- Facilitating the release of long-pending payments to wind energy generators after several rounds of representations at the highest level.
- Making available best-in-class practices in wind energy generation through international conferences and seminars, etc.
- Monetising Carbon Credits for generators.

What we do

Participate

Actively participate with government in formulation of policy, rules and regulations pertaining to the wind sector

Liaise

Closely liaise with Central and State Government and other agencies on matters affecting the wind energy sector and the interests of our members

Promote and Protect

Promote and protect the common interests of our members

Collect and disseminate

Collect and disseminate statistical, technical and other information regarding wind energy sector

Affiliate

Affiliate with organisations having similar objectives

Committees

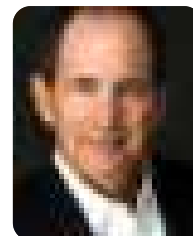
ADVISORY COMMITTEES



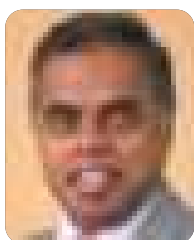
Dr Anil Misra
Former National
Project Manager,
UNIDO



Dr Gnana Gandhi
Senior Vice-President
Propulsion, Skyroot
Aerospace Pvt Ltd.



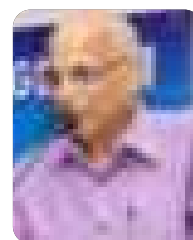
Dr James P Seaba
Program Director, ARPA-E,
U.S. Department of Energy,
Washington, DC, USA



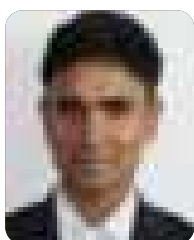
Mr Mariasundaram Antony
CEO, Gorlan India
Switchgears Pvt Ltd,



Dr V Narayanan
Distinguished Scientist &
Director, ISRO



Dr K Ramamurthy
Former Director, ISRO
and Professor IIT (Madras)



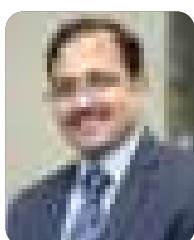
Mr Srinath Ravichandran
Co-Founder & CEO,
Agnikul Space Startup



Mr Krishnan Sadagopan
Senior Vice President, Engine Development,
Ashok Leyland & Independent Director,
Indian Oil Corporation Limited



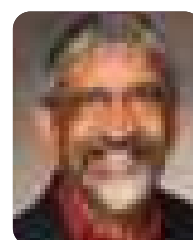
Dr Sanak Mishra
Former Managing Director,
Rourkela Steel Plant



Dr Senthilarasu Sundaram
Professor, School of Computing,
Teesside University,
United Kingdom



Mr Umesh Sahdev
Executive Chairman,
Hydrogenium Resources Pvt. Ltd.,



Dr Vikram Rao
Executive Director,
Research Triangle Energy
Consortium, Durham,
North Carolina, USA

Committees

ORGANIZING COMMITTEES

Chief Patron



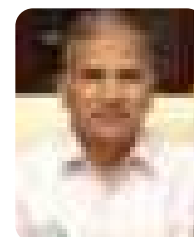
Shri L Gopalakrishnan
Managing Trustee,
PSG Institutions

Patron



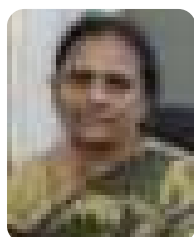
Dr K Prakasan
Principal,
PSG College of Technology

Conference Chair



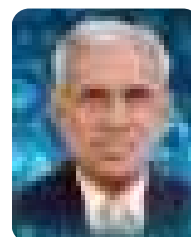
Dr R Rudramoorthy
Director,
PSGCARE

Conference Academic Chair



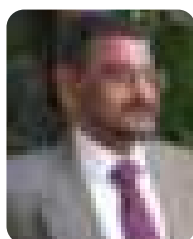
Dr P R Thyla
Prof & HoD, Dept. of Mechanical Engg,
PSG College of Technology

Conference Industrial Chair



Dr K Kasthurirangaian
Chairman,
Indian Wind Power Association

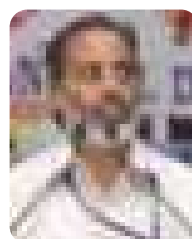
Conference Co-Chairs



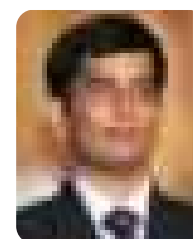
Dr G (Subbu) Subbaraman
Institute Fellow,
GTI Energy, USA



Dr Jayanta Kapat
Professor,
University of Central Florida, USA



Dr S Sankaran
Chief General Manager,
Indian Space Research Organization



Dr Satyanarayanan Seshadri
Head Energy Centre and
Energy Consortium, IIT Madras

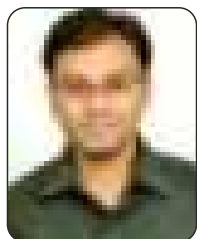
Committees

Conference academic co-chair

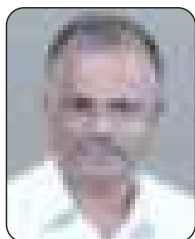


Dr V Prabhu Raja
Professor(CAS),
Dept. of Mechanical Engg., PSGCT

Organizing secretaries



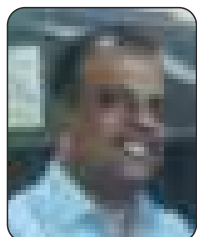
Dr T Prabu
Professor, Dept. of
Mechanical Engg., PSGCT



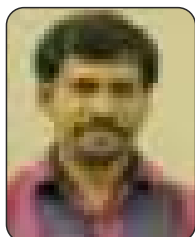
Dr K Mayilsamy
Professor, Dept. of
Mechanical Engg., PSGCT



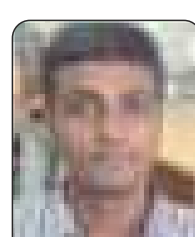
Dr P Karthikeyan
Professor, Dept. of
Automobile Engg., PSGCT



Dr P Viswanathan
Associate Professor, Dept. of
Mechanical Engg., PSGCT



Dr S Babu
Associate Professor, Dept. of
Mechanical Engg., PSGCT



Dr R Arun Kumar
Assistant Professor, (Sr.Gr), Dept. of
Mechanical Engg., PSGCT

Technical



Dr K Ragu
Professor(CAS)



Dr K Punitha Rani
Associate Professor(CAS)



Dr A P Senthil Kumar
Associate Professor(CAS)



Dr R Jegathish Kumar
Assistant Professor(CAS)

Committees

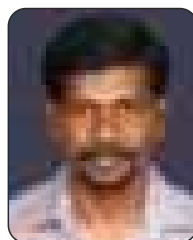
Publication



Dr K Kannan
Professor (CAS)



Dr R Velavan
Professor

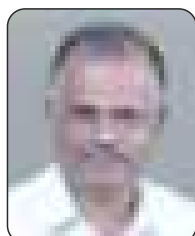


Dr S Babu
Associate Professor



Dr R Venkatesh
Assistant Professor (Sl.Gr.)

Programme



Dr K Mayilsamy
Professor



Dr A Ramesh Babu
Professor



Dr M Parthiban
Assistant Professor(Sl.Gr.)

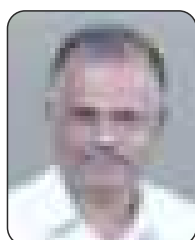


Dr P Govindraj
Assistant Professor (Sl.Gr.)



Mrs B Vaishnavi
Associate Professor

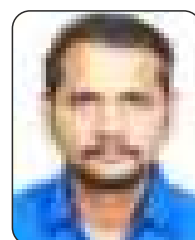
Hall arrangement



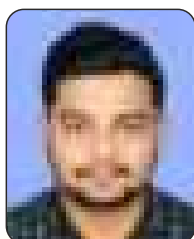
Dr R Sridhar
Assistant Professor



Dr P Nallasamy
Assistant Professor



Dr A Adhiyamaan
Assistant Professor (Sl.Gr.)



Mr A Mohan
Assistant Professor



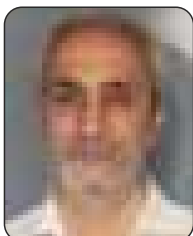
Dr Arun Ramnath R
Associate Professor (Sl.Gr.)

Committees

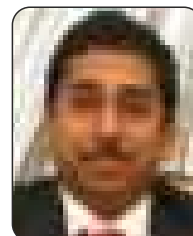
Public Relations & Media



Dr S Udhayakumar
Assistant Professor



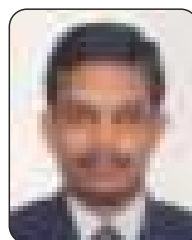
Dr V Jaiganesh
Associate Professor



Dr S Syath Abuthakeer
Associate Professor



Dr N Ganesh Kumar
Associate Professor



Dr R Prakash
Assistant Professor (Sl.Gr.)

Hosting



Dr S P Vendan
Professor (CAS)



Mr T Anantharaj
Assistant Professor



Dr V Vijayakumar
Assistant Professor (Sl.Gr.)



Dr A S Prasanth
Associate Professor

Transport and accommodation



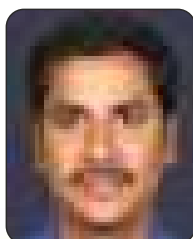
Dr A Prabhukarthi
Assistant Professor



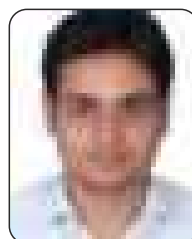
Mr K Sadesh
Assistant Professor



Mr N Mathimurugan
Assistant Professor (Sl.Gr.)



Dr P Dhanabal
Assistant Professor (Sl.Gr.)



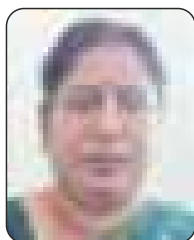
Dr P Govindraj
Associate Professor (Sl.Gr.)

Committees

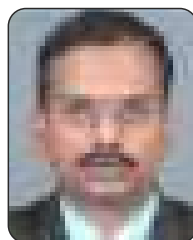
Registration



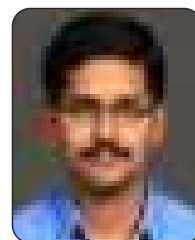
Mr C Manoharan
Associate Professor



Dr R Jayachitra
Associate Professor (CAS)



Mr D Shanmuga Sundaram
Assistant Professor

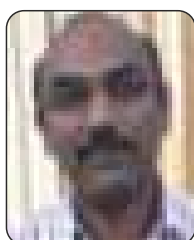


Dr M Kalayarasan
Assistant Professor (Sl.Gr.)

Accounts



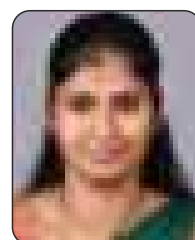
Dr M Yuvaraja
Associate Professor



Dr D Martin Sureshbabu
Assistant Professor



Mr S Samsudeensadham
Assistant Professor

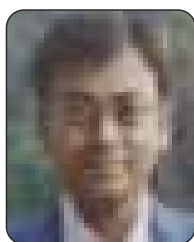


Mrs M Gomathi Prabha
Assistant Professor

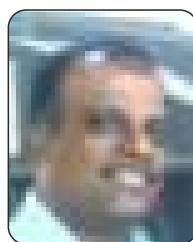
Advertisement & Sponsorship



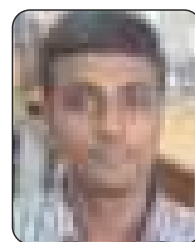
Dr J Kanchana
Professor



Dr T Prabu
Professor

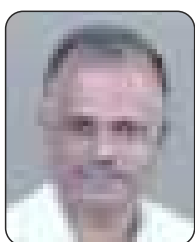


Dr P Viswanathan
Associate Professor



Dr R Arun Kumar
Assistant Professor (Sr.Gr.)

Purchase



Dr K Mayilsamy
Professor



Dr D Rajenthirakumar
Professor

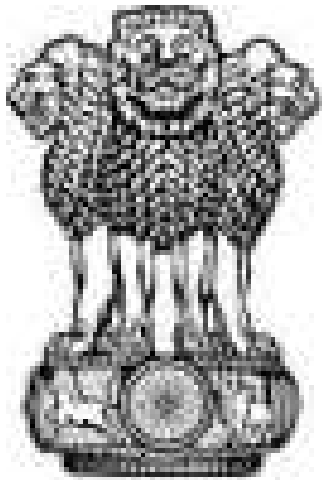


Dr V Vijayakumar
Associate Professor (Sl.Gr.)



Dr T Karthik
Assistant Professor (Sl.Gr.)

Prestigious Sponsors

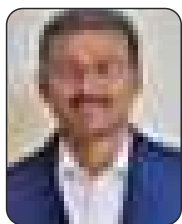


सत्यमेव जयते

विज्ञान एवं
प्रौद्योगिकी मंत्रालय
MINISTRY OF
**SCIENCE AND
TECHNOLOGY**



Speakers



Dr Balaji Srinivasan

Head of Engineering,
Bosch Global Software
Technologies Private Limited,
Coimbatore



Mr R Chellappan

Founder and
Managing Director,
Swelect Energy Systems Ltd



Mr David Jayanth Isaac

R&D Specialist &
Project Manager,
Cement Green Innovation,
FLSmidth



Mrs Disha Agarwal

Senior Programme Lead,
Council on Energy,
Environment And Water,
New Delhi



Mr Gaurav Kumar

R&D Manager, Industrial
Steam Turbines & Auxiliaries,
Siemens Energy



Mr G D Gopalakrishnan

CEO -Sulochana Cotton
Spinning Mills Pvt Ltd



Mr K N Jayashankar

Project Lead,
ENERCON



Dr Karunamoorthy

Managing Director,
Windplus Pvt Ltd and
Honorary Treasurer,IWPA



Dr Keerthivasan Rajamani

Assistant Professor,
University TWENTE, Netherlands



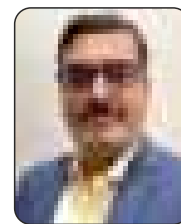
Mr Kumar Duraiswamy

Joint Secretary,
Tiruppur Exporter's Association



Mr Nishant Attri

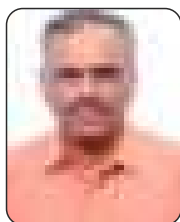
Chief Manager,
Sustainable Energy Systems,
Siemens Energy



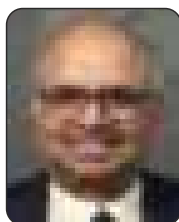
Mr Rahul Wagh

Senior Engineering Manager,
Innovation, Research & Technology,
Baker Hughes.

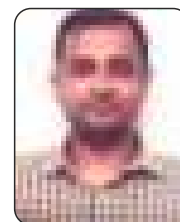
Speakers

**Dr K S Reddy**

Professor,
IIT Madras

**Dr Sarma V Pisupati**

Professor,
The Pennsylvania State University, USA

**Mr Sayantan Paul**

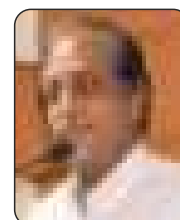
R&D Team Lead,
Siemens Energy

**Mr Selvaraji Muthu**

Senior General Manager,
MAHLE Engine Components
India Private Limited

**Mr P Srinivasa Rao**

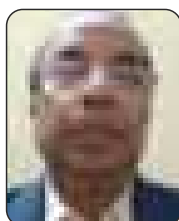
General Manager,
Cryo Propellant Systems,
SDHC SHAR, ISRO

**Dr R Sethu Madhavan**

Energy Advisor, GSH Group,
Integrated Facilities Management,
Chennai

**Dr Sujit Sopan Barhate**

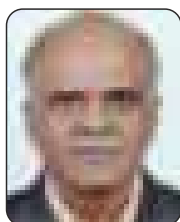
Senior Chief Engineer and Head EV R&D,
CREAT UNO MINDA,
Pune, Maharashtra, India

**Dr Sunil Sarangi**

Professor,
IIT, Kharagpur

**Dr Sushil S Ramdasi**

Deputy Director,
In Charge -Power Train Design,
ARAI, Pune

**Mr A D Thirumoorthy**

Energy Consultant,
Chief Technical Advisor,
Indian Wind Power Association

**Mr Umang Swaroop**

Manager,
Siemens Energy

**Mr Vipindas Othiyil**

Head of engineering,
Bosch Global Software Technologies
Private Limited (GSE)

Global Conference on Decarbonizing India

PROGRAMME SCHEDULE

December 15, 2023

Day 1

TIME SLOT	SESSION	SPEAKERS	TOPICS
11.30 -11.45	Renewable Energy-Wind Panel	Dr. K Kasthurirangaian, Chairman, Indian Wind Power Association (IWPA) - Moderator	Accomplishments from Wind Energy
11.45-12.00		Mrs Disha Agarwal, Senior Programme Lead, Council on Energy, Environment And Water	Winds of change for India's power sector transition
12.00-12.15		Dr Karunamoorthy, Managing Director, Windplus Pvt Ltd.	Sustainability Integration for Future Business Management
12.15-12.30	Renewable Energy-Solar Panel	Dr K S Reddy, Professor, Department of Mechanical Engg, IIT (Madras) - Moderator	Moderator Energy Storage System for Improvement of Reliability of CSP Plants
12.30-12.45		Mr A D Thirumoorthy, Energy Consultant, Chief Technical Advisor, Indian Wind Power Association	Role of Solar Power in Decarbonising Activity
12.45-01.00		Mr R Chellappan, Founder and Managing Director, Swelect Energy Systems Ltd	Solar Energy – The best form of Green Energy with high level of flexibility and scalability
01.00 -02.00	Lunch		
02.00 -02.10	Green Hydrogen	Dr (Subbu) Subbaraman, Institute Fellow, GTI Energy, USA-Moderator	Challenges in Green Hydrogen
02.10-02.20		Dr V Narayanan, Distinguished Scientist & Director, ISRO, India	Cryogenic Propulsion System
02.20-02.30		Mr Nishant Attri, Chief Manager, Sustainable Energy Systems, Siemens Energy	Carbon Capture Utilization and Storage and Green Hydrogen
02.30-02.40		Mr P Srinivasa Rao, General Manager, Cryo propellant Systems, SDHC SHAR, ISRO	Design of liquid hydrogen storage and transfer systems
02.40-02.50	Industry	Dr Senthilarasu Sundaram, Professor of Sustainable Energy Materials, Teesside University, Tees Valley, United Kingdom-Moderator	Materials innovation for Perovskite solar cells efficiency and lifetime increase
02.50-03.00		Mr David Jayanth, R&D Specialist & Project Manager, Cement Green Innovation, FLSmidth	Decarbonization Pathways for Cement Industry

Global Conference on Decarbonizing India

PROGRAMME SCHEDULE

December 15, 2023

Day 1

TIME SLOT	SESSION	SPEAKERS	TOPICS
03.00-03.10	Industry	Mr Kumar Duraiswamy, Joint Secretary Tiruppur Exporters' Association	Tiruppur An ESG Compliant Cluster
03.10 –03.20	Energy Technologies	Mr Mariasundaram Antony, CEO, Gorlan India Switchgears Pvt.Ltd - Moderator	Driving Energy Transition across the Energy Value Chain
03.20-03.30		Dr Anil Misra, Formal National Project Manager, UNIDO	The Role of Renewable Energy in Sustainable Development
03.30-03.40		Mr Rahul Wagh, Senior Engineering Manager, Innovation, Research & Technology, Baker Hughes	Energy Transition through Technology Leadership
03.40-03.50		Mr Umang Swaroop, Manager, Siemens Energy	Heat pump
03.50-04.00		Mr G D Gopala Krishnan, CEO -Sulochana Cotton Spinning Mills Pvt Ltd	Used Pet bottles into Lovely Garments
04.20-04.30	Transportation	Dr Jayanta Kapat, Professor, University of Central Florida, USA - Moderator	Ammonia as an Energy-Carrier for Hard-to-Decarbonize Transportation Sectors
04.30-04.40		Mr Selvaraji Muthu, Senior General Manager, MAHLE Engine components India Private Limited	MAHLE Advanced Products technologies for Carbon-neutral Powertrains and New Energy Vehicles
04.40-04.50		Dr. Sushil S Ramdasi, Deputy Director, In Charge -Power Train Design, ARAI, Pune	Challenges and Opportunities in Indigenisation of E Mobility from an Indian Perspectives
04.50-05.00		Mr. Vipindas Othyttil, Head of engineering, Bosch Global Software Technologies Private Limited.	Hydrogen based technology for mobility and stationary applications
05.00-05.10		Dr. Balaji Srinivasan, Head of Engineering, Bosch Global Software Technologies Private Limited	
05.10-05.20		Dr.Sujith Sopan Barhate, Senior Chief Engineer and Head EV R&D, CREAT UNO MINDA, Pune	Diagnosing fuel cell in automotive applications-Online, Non-invasive and non-destructive
05.20-05.30		Dr.Sarma V. Pisupati, Professor, The Pennsylvania State University,USA	Is Decarbonizing the Industrial Sector Possible without a Sustainable Mineral Supply?- Online (5.20PM-IST)

Global Conference on Decarbonizing India

PROGRAMME SCHEDULE

December 16, 2023

Day 2

TIME SLOT	SESSION	SPEAKERS	TOPICS
09.30 -09.45	Keynote Speaker	Dr. Sunil Sarangi, Professor, IIT, Kharagpur	Cryogenic Engineering
09.45-10.00		Mr.Gaurav Kumar, R&D Manager, Industrial Steam Turbines & Auxiliaries, Siemens Energy	Compressed Air Energy Storage
10.00-10.15		Mr.Sayantan Paul, R&D Team Lead, Siemens Energy	Waste Heat Recovery (ORC)
10.15-10.30		Mr. Krishnan Sadagopan, Sr. Vice-President- Engine Development, Ashokleyland	Mobility Trends In Decarbonisation
10.30-10.45		Dr.R.Sethu Madhavan, Energy Advisor GSH Group, Integrated Facilities Management, Chennai	Decarbonization in Industries thro' Adoption of Energy Efficiency & Renewables : Selected Case Studies Showcased
10.45-11.00		Dr.Keerthivasan Rajamani, Assistant Professor, University TWENTE, Netherlands Online	CO2 capture – Overview and insight
11.00-11.15		Mr. K N Jayashankar, Project Lead, ENERCON - Online	wind turbines and the technology trends in the renewable energy field
Paper Presentation			
11.30 -11.45	Energy Technologies & Renewable Energy Systems	23150-Computational Analysis of a Double Pipe Heat Exchanger With and Without Inserts	A S Krishnan
11.45-12.00		23116-Standardization of fermentation conditions for production of bio-ethanol from matured coconut water	R.S. Vidhya Ganesh, R. Parimala Devi*
12.00-12.15		23118-Removal of fermentation inhibitor to maximize the bioethanol production	K. Chandrakumar, S. Sriramajayam
12.15-12.30		23106-Scenario of Solar Photovoltaic Water Pumping System	Aravind Kumar M, Dr. S. Christopher
12.30-12.45		23101-Energy recovery devices for Desalination	Manikandan Sakthivel
12.45-01.00		23138-Investigation of different origin fired oils and its bio diesel using gas chromatography-FID Chromatogram	Arruthra V, Dawn SS

Global Conference on Decarbonizing India

PROGRAMME SCHEDULE

December 16, 2023

Day 2

TIME SLOT	SESSION	SPEAKERS	TOPICS
01.00 - 01:15	Energy Technologies & Renewable Energy Systems	23143-Identification of Optimum Location and Designing of Sustainable Charging Stations for Electric Vehicles using GIS – A Case Study Towards a Sustainable City	Thilagam A, Babu S, Siddharth Krishna, Vasanth Ragul, Ragul Adithya, Rakshit, Dhanush Raghav, Dharani
01.15 - 02.00	Lunch /Poster Presentation		
02.00 - 02.15	Green Hydrogen & Transportation	23153-Configuring the pilot Gas Generator with Green propulsion systems	S.Sankaran, A Rajarajan
02.15 - 02.30		23102-Revolutionizing Maritime Transport: A Blueprint for Sustainable Mobility - Conceptualizing an Electric Roll-On/Roll-Off (RO-RO) Ferry System for India's National Waterway 3	Aravind KR
02.30 - 02.45		23117-Co-pyrolysis of plastic waste and lignocellulosic biomass for high-recovery fuel oil	J.Gitanjali, S. Karthikeyan
02.45 - 03.00		23120-A Noval Battery charging method for plug in fuel cell hybrid electric vehicle	Kashyap Prabhakar, Sujit Barhate , Homeshkumar Dave and Girish Kamble
03.00 - 03.15		23111-Proton Exchange Membrane Fuel Cell: Bi-Polar Plate (BPP) Design Concepts	R. Bhoobathi, Karthikeyan P
03.15 - 03.30		23112-Effect of cross-sectional geometry in flow behaviour: A steady state computational study	Vijai Kaarthi V, Karthikeyan P
03.30 - 03:45		23114-Effect of Manifold and Distributor Dimension on Flow Characteristics in PEM Fuel Cell Stack	Dineshkumar P and Karthikeyan P
03.45 - 04.00	Decarbonization & Carbon Capture	23122-Carbon capture & storage potential in India	Surya Prabhakaran M, Prabu T
04.00 - 04.15		23115-Electric vehicle battery pack cooling using model predictive control strategy under different driving conditions	Parthiban V, Vijay Karthi V, Karthikeyan P
04.15 - 04.30		23104-CO2 dehydration for CCUS	Venkatesan Jayaraman

Global Conference on Decarbonizing India

PROGRAMME SCHEDULE

December 16, 2023

Day 2

TIME SLOT	SESSION	SPEAKERS	TOPICS
04.30 - 04.45	Decarbonization & Carbon Capture	23141-Syntropic agroforests and their potential to combat GHG emissions and to conserve water while providing a revenue to the government	Dr Asha Nair, Dr Prabhu Thangadurai, Dr N Vivek
04.45 - 05.00		23126-Innovation and Eco Design for Sustainability	Vignesh Kanna M, Udhayakumar E, Prabu T
05.00 - 05.15		23121-Recent trends on climate impact of plastics and exploring sustainable alternative for a greener future	PM Surender, Iniyan K, Prabu T
05.15 - 05.30		23124-Green Technology To Minimizing Carbon Footprint For Lubricants	Yashwanth Kumar S, Prabu T
05.30 - 05.45		23136- Climate vulnerability and financial indicators of countries	Dr.D.Susana, Dr.V Srividya, Ms R R Sathya
05.45 - 06.00		23156 - Impact of Quantum Locking in Sustainable Manufacturing Practices	Dinesh Krishnaa, Nashreen J, Syath Abuthakeer S



India's First Solar Finishing Plant



Over 34% solar projects India and overseas



Installed over 10,000 solar PV Projects - Utility scale, Rooftop and Solar Water Pump



40 years experience in design & power conditioning systems



100 MW capacity with large market capitalisation



Top 1 Solar PV module manufacturer according to IHS



SWELECT 100 MW state-of-art manufacturing facility at Coimbatore, India



100 MW of multi-standby-cumulative facility in Switzerland



ISO 9001, ISO 14001, and ISO 45001 certified and AEM approved Solar PV modules



ISO 9001:2015, ISO 14001:2015, and ISO 45001:2018



Excellent after-sales service across 250 locations



An independent Power Purchase Agreement with 50% projects developed under various national and solar schemes



Strong business ties with other customers from corporates, banks, Govt, Educational, Industrial etc.



Various business models for solar power projects with approximately 1000 PV modules and complete balance of system with EPC, O&M, and maintenance

swelect
ENERGY SYSTEMS LIMITED

POWER DIVISION, SWELECT LIMITED, COIMBATORE

SWELECT 100 MW PV & PV Systems Ltd. Coimbatore, Coimbatore, India
M. 94420 94420, P. 94420 94420, F. 94420 94420
Email: info@swelectes.com, swelect@coimbatore.swelectes.com
100 MW PV & PV Systems Ltd. Coimbatore, Coimbatore, India

22 Million MTPA

12 Manufacturing Facilities across India

400 MW Power Generation *Ranks Top in Green Power Generation in Cement Industry*



CENTRE FOR SCIENCE AND ENVIRONMENT
GREEN RATING PROJECT
AWARDS **4 LEAVES** to

MADRAS CEMENTS LIMITED — ALATHIYUR WORKS

- for leadership in point source and fugitive dust control
- for leadership in technology and energy efficiency
- for leadership in utilisation of waste material

Presented by Dr M S Swaminathan
Chairperson of Centre for Science and Environment

Sunita Narain
Director
CSE



December 16, 2005
New Delhi

Ramco is the only cement company to win the prestigious '4 Leaves Award'.

Keynote Speakers



Mrs Disha Agarwal

Senior Programme Lead,
Council on Energy,
Environment And Water, New Delhi

Topic: Winds of change for India's power sector transition

India's rapidly rising electricity demand must be met reliably and cost-effectively while decarbonizing the power system at the same time. India is advancing towards 500 GW of clean power capacity by 2030, and wind power is one of its two mainstays to get there. With 44 GW of wind capacity installed today, there is still a long way to go. Research by the Council on Energy, Environment and Water (CEEW) shows that for India to reach net zero emissions by 2070, its wind capacity must reach 557 GW by 2050 and 1,792 GW by 2070. Unfortunately, the growth of India's wind sector has slowed down since 2017 because of various challenges and evolving risks. We must maximize the utilization of India's wind resources for building a sustainable, affordable, secure and resilient power system. And, for that to happen, we must bring some paradigm shifts that can help de-risk the sector and realize its benefits. My talk will highlight the importance of wind as a resource, current and emerging risks in the sector, paradigm shifts that are needed, and discuss the avenues for accelerated growth and contribution of the sector.

Keynote Speakers



Dr Karunamoorthy

Managing Director,
Windplus Pvt Ltd and
Honorary Treasurer, IWPA

Topic: Sustainable Integration For Future Business Development

In the global agenda, sustainable development is the chief objective spanning both geographic and economic borders. The Sustainable Development Goals (SDGs) include clean energy, climate change, industry, innovation, and infrastructure expansion as well as sustainable cities and communities, heavily depends on energy. To provide an overall framework, sustainable integration aims to lead energy conservation, conversion, renewable technology penetration, and improved energy efficiency. The identification of parties and roles of producers, users, aggregators, etc., cross-cutting technologies, energy-related products and services, various country, city, district, single building unit, and the energy, environmental, social, and economic impacts of sustainable. The three Rs – Deeper thinking to Reflect, minimal life approach to Refine and to innovate and explore to Re-construct lead a new path by innovating the new technique to implement in a sustainably benign approach. With the presidency theme, One Sun One World One Grid, marching towards One Earth, One Family, One Future. Let us Protect our earth today for our children's tomorrow.

Keynote Speakers



Dr K S Reddy

Professor,
IIT, Madras

Topic: Energy Storage System for Improvement of Reliability of CSP Plants

Renewable energy based decentralized energy system is a viable approach to meet the basic energy needs of both rural and urban regions. The concept of hybrid renewable energy technologies has been discussed and developed in a large scale for both urban and rural electrification. The principle cause for choosing hybrid technologies is to overcome the inconsistency of power generation in conventional means. The smart integration of different renewable technologies not only balances the annual energy output but also can complement each other to avoid energy storage requirement and improve the overall efficiency of the system. In the recent years, plenty of research on integrating solar and biomass energy system are under the spotlight as it helps in self-sufficient and sustainable rural electrification and also boosts the native community to utilize the bio-waste comprehensively. High temperature heat production for electricity generation often requires direct absorption of solar energy. Solar thermal electric power systems promise to be most cost effective renewable energy systems to displace fossil fuels. Concentrating Solar Power (CSP) technology is among the front-runners in main stream technologies developed so far. The CSP plants are turning out to be one of the most entrusted technologies for transforming solar energy into electricity on a large scale. The solar parabolic dish with receiver configuration is often referred as most efficient system. To address the intermittency in solar energy system due to unforeseen weather conditions and to improve dispatchability, the requirement of Thermal Energy Storage (TES) system is becoming increasingly inevitable. It has been an undisputed fact that a substantial cost reduction in concentrated solar thermal power plants can be achieved by incorporating TES system, which facilitates heat for extended duration and henceforth multiplying the operational capacity of the power plant and at the same time augmenting the ability of power dispatch. The present work is intended to investigate the TES thermocline system for CSP plants with different HTFs namely therminol oil, Solar Salt and HITEC. Various HTFs are studied by taking discharge effectiveness as a pivotal parameter to analyze the influence of bed porosity, HTF, design and operating parameters. As high temperature operation improves the CSP cycle efficiency, a detailed plant-level analysis with extended and seasonal thermal energy storage may give extent of reliability improvement and cost-effectiveness.

Keynote Speakers



Mr A D Thirumoorthy

Energy Consultant,
Chief Technical Advisor, IWPA

Topic: Role of Solar Energy in Decarbonization

Climate change is a global emergency that is affecting the planet in the most detrimental ways. To keep global temperatures from rising beyond the danger threshold, the world must reduce emissions from many activities of the society. This responsibility is for all the sectors. All are important players in decarbonizing the world and creating a low-carbon pathway. With solar energy being one of the most abundant renewable resources available, it has become a critical part of limiting carbon emissions and achieving carbon neutrality. Solar is a clean source that can provide businesses with affordable and reliable power without creating new negative externalities for both the environment and society. Decarbonization is the process of reducing carbon dioxide (CO₂) emissions through the application of low-carbon or NO Carbon energy sources and achieving a lower output of greenhouse gas emissions. For businesses or Industry to decarbonize, they must reduce the amount of carbon they generate from their operations. Limiting the number of carbon emissions from businesses is a keyway to greatly help in decarbonizing the world. Through a low-carbon pathway, the rate of global warming can be slowed down for a better chance of surviving the adverse effects of climate change.

Solar energy is environmentally friendly technology, a great energy supply and one of the most significant renewable and green energy sources. It plays a substantial role in achieving sustainable development energy solutions. Therefore, the massive amount of solar energy attainable daily makes it a very attractive resource for generating green electricity. Both technologies, applications of concentrated solar power (thermal) or solar photovoltaics, are always under continuous development to fulfil our energy needs. Hence, a large installed capacity of solar energy applications, supports the energy sector. This paper highlights solar energy applications and their role in sustainable development and considers renewable energy's overall employment potential. Thus, it provides insights and analysis on solar energy sustainability, including environmental and economic development. The history of solar energy can be traced back to the seventh century when mirrors with solar power were used. In 1893, the photovoltaic (PV) effect was discovered; after many decades, scientists developed this technology for electricity generation. Based on that, after many years of research and development from scientists worldwide, solar energy technology is classified into two key applications: solar thermal and solar PV.

PV systems convert the Sun's energy into electricity by utilizing solar panels. These PV devices have quickly become the cheapest option for new electricity generation in numerous world locations due to their ubiquitous deployment. For example, during the period from 2010 to 2018, the cost of generating electricity by solar PV plants decreased by 77%. However, solar PV installed capacity progress expanded 100-fold between 2005 and 2018. Consequently, solar PV has emerged as a key component in the low-carbon sustainable energy system required to provide access to affordable and dependable electricity, assisting in fulfilling the Paris climate agreement and in achieving the 2030 SDG targets. Solar Energy has been developed as a key captive energy source for all industries and business houses. Roof top solar also is being promoted with net metering facilities. Hence solar energy finds a place in all walks of life to reduce carbon emissions.

Keynote Speakers



Mr Nishant Attri

Chief Manager,
Sustainable Energy Systems,
Siemens Energy

Topic: Carbon Capture Utilization and Storage and Green Hydrogen

Carbon Capture Utilization and Storage: India is the 3rd largest emitter of CO₂ in the world after China and the US, with estimated annual emissions of about 3.4 gigatonne per annum (gtpa). The Government of India has committed to reducing CO₂ emissions by 50% by 2050 and reaching net zero by 2070. The growth of renewable power capacity has been one of the key success stories of the clean energy transition in India; however, the power sector only contributes to about 1/3 rd of the aggregate CO₂ emissions, which will continue to abate as renewables increasingly replace fossil fuel-based power generation. The growing industrial economy emits close to another third of the aggregate emissions that are hard to abate and will continue to increase unless new technologies and carbon abatement mechanisms are deployed. At the same time, while India phases down the use of coal over time, India will be dependent on fossil energy sources like coal for a long time to support the industry and meet the requirements for affordable and reliable baseload power. Therefore, India's decarbonization pathway must also embrace technologies which will abate emissions from the hard to abate industrial sectors as well as for residual baseload power generation.

Carbon Capture Utilization and Storage (CCUS) has an important and critical role to play in decarbonizing the industrial sector, which is hard to electrify and hard to abate, due to the use of fossil fuels not only as a source of energy but within the process itself. CCUS also has an important role to play in decarbonizing the power sector, given India's present reliance on coal for meeting over 70% of its electricity needs. Even if India can substantially green the grid and meet the target of 500 GW installed capacity of renewables by 2030, there would still be a need to meet the baseload power demand from fossil fuels (most likely coal) or other dispatchable sources, given the intermittency and non-dispatchable nature of solar and wind power.

Green Hydrogen: India's deep commitment to aspirational Climate Goals has been widely acknowledged in the comity of nations. Our achievements have matched our ambition. India has the fastest growing Renewable Energy capacity in the world. India has also emerged as one of the most attractive destinations for investments in Renewables. As India has set its sight on becoming energy independent by 2047 and achieving Net Zero by 2070, we recognize the critical role of Green Hydrogen. India, with its vast renewable energy resources, also has the opportunity to produce Green Hydrogen for the world. The National Green Hydrogen Mission aims to provide a comprehensive action plan for establishing a Green Hydrogen ecosystem and catalyzing a systemic response to the opportunities and challenges of this sunrise sector.

Keynote Speakers



Dr Senthilarasu Sundaram

Professor of Sustainable
Energy Materials,
School of Computing,
Engineering and Digital Technologies,
Teesside University, United Kingdom

Topic: Materials innovation for Perovskite solar cells efficiency and lifetime increase

Sustainable energy generation for the net zero applications are prime focus of the “Sustainable Energy Materials” group in the Teesside University. The focus of the research is to obtain net zero capacity in materials, devices, and systems development. The major focus of the group is to innovate materials, applying circular economy concepts for Energy-Food-Water-Healthcare nexus problems and extending its impact towards society. The energy efficiency in the buildings, water remediation and focusing on perovskite solar cell is the main part of this presentation. The carbon materials used to achieve room temperature stability and efficiency increment. The materials innovation towards each layer in the perovskite solar cells are giving importance in this presentation.

Keynote Speakers



Mr David Jayanth Issac

R&D Specialist & Project Manager,
Cement Green Innovation,
FLSmidth

Topic: Decarbonization Pathways for the Cement Industry

With rapid urbanization and economic growth in developing countries set to drive cement demand over future decades, the quest to decarbonize its production is accelerating. Currently accounting for 7-8% of global annual CO₂ emissions, the world's leading cement and concrete manufacturers have pledged to cut their CO₂ emissions by 25% by 2030, and to be net zero by 2050. Key to delivering these goals will be the modernization of existing cement plants. These assets are designed to operate for many decades in order to achieve maximum ROI: technologies that reduce the carbon intensity of cement production should therefore be integrable into these existing production sites to provide the best business case for decarbonization and avoid a fleet of stranded assets.

Emissions from energy: Many cement plants still rely on fossil fuels to generate the large amount of thermal energy needed for cement production: combustion of these fuels accounts for 32% of the industry's total carbon emissions. Traditional decarbonization methods have focused on efficiency improvements to reduce that energy demand; however, the emission reduction potential of such improvements is very limited. Reducing the reliance on fossil fuels is thus the first key step on the path to net zero cement: a switch that all plants can make with available technologies via the substitution of fossil fuels with alternative waste-derived fuels (e.g., combustible municipal waste, biomass, non-hazardous industrial or commercial wastes). These fuels offer a much more economic and practical way forward than expensive green hydrogen or electrification of the process, which would rely on prior decarbonization of the power grid.

Process emissions: 55% of cement-related CO₂ emissions occur as a result of the calcination of limestone during clinker production. These so-called process emissions make cement a hard to abate sector. Using less clinker in cement or less concrete in construction design thus has tremendous decarbonization potential. Blended cements – in which a proportion of clinker is substituted by supplementary cementitious materials (SCMs), fillers, and additives – have the potential to significantly reduce carbon emissions. Typical substitutes include fly ash, natural pozzolans, slag, and calcined clay. These do not release CO₂ through calcination, and many can be activated in a carbon-neutral way. In

addition, the re-use of concrete and demolition waste, either as an upcycled aggregate, components in the raw meal or by reprocessing the used cement, offers circularity. However, such changes will require altering a cement manufacturing process that has been optimized over centuries, as well as adapting established building codes and construction design standards.

Finally, given the limitations of what can be achieved within the bounds of the existing cement process, scaling up carbon capture utilization and storage (CCUS) will be necessary if the industry is to achieve its net zero targets. Many different end-of-pipe capture technologies are available today; however, all are as costly as operating the cement plant itself. Technologies that produce a pure stream of CO₂ are being developed, including oxyfuel, direct separation of the process of CO₂, and electrification. These reduce the cost of carbon capture by eliminating the need for large end-of-pipe capture units. On the other hand, the utilization of captured CO₂ provides an avenue for the industry to close its carbon loop. Mineral carbonation is the most actively pursued solution here and involves the mineralization of CO₂ to produce regular or lightweight aggregates; a carbonated SCM can also be produced by similar processes. CO₂ can also be injected directly into wet concrete for curing.

Achieving change will be challenging. While digital transformation and performance optimization make good business sense and can be implemented easily from the inside, changing the cement mix requires more of an 'outside-in' approach. Similarly, eliminating fossil fuels from the process is not something the cement industry can do alone. Developing waste streams suitable for cement kilns and ensuring there is sufficient renewable power generation are endeavors that must be shared with other industries. Change in this area will be driven by policymakers and by customers, who must demand more eco-friendly cement.

Keynote Speakers



Mr Mariasundaram Antony

CEO, Gorlan India
Switchgears Pvt Ltd,

Topic: Driving Energy Transition across the Energy Value Chain

When we talk about Energy Value Chain we essentially mean the whole chain from the point of exploration to the point of consumption of energy. It is a value chain because at every point we have been generating economic value and making the energy accessible, affordable but not in a carbon neutral or greener way. So energy transition is about making this whole value chain greener than today in the short term but in the long term make it zero carbon or decarbonize completely. Is this possible or doable? That is the big question in everyone's mind. In this presentation I would like to walk through the key aspects of the Energy value chain and talk about what Energy transition/decarbonization means for each of these. In today's context, the effect of greenhouse gasses on the overall climate of the planet has been impacted severely and this has created a sense of urgency for decarbonization in every sector of the economy. The energy sector is one of the key sectors contributing to global warming because today across the whole value chain we are net emitters of greenhouse because of the extraction of fossil fuels and burning of fossil fuels for generation of Power. Today more than 50% of the global energy capacity is driven by burning of fossil fuels in the form of coal power & Gas Power and there is an urgent need to decarbonize these form of energy production. From the point of exploration there are significant steps being taken by the companies traditionally involved in Fossil fuel extraction to strategically move away from it over a period of time and also be carbon neutral to start with and then decarbonize the business model which they have today. Similarly the generation companies are driving increased penetration of greener energy in their overall capacity through improvements and new growth to support the energy transition strategy. In the transmission and distribution part of the value chain, there are ample examples of adopting greener options like using green gasses instead of SF6 traditionally used of Switchgears and then adopting greener options for transformer cooling. Additionally multiple renewable energy options are being looked into interns of captive power requirements in sub-stations which traditionally used to have diesel based emergency back up solutions. At the consumption level there is increased awareness to use more of the greener energy by accessing it at the open market and then ensuring better reliability with greener back up solutions like batter energy storage systems. In summary there are challenges in driving energy transition towards decarbonization but it is a necessity than a choice in today's global warming scenario. Being aware of the different options to enable that and learning from each other will help to accelerate the pace of energy transition.

Keynote Speakers



Dr Anil Misra

Former National
Project Manager,
UNIDO

Topic: The Role of Renewable Energy in Sustainable Development

The bulk of greenhouse gases that blanket the Earth and trap the sun's heat are generated through energy production, by burning fossil fuels to generate electricity and heat. Fossil fuels, such as coal, oil and gas, are by far the largest contributor to global climate change, accounting for over 75 percent of global greenhouse gas emissions and nearly 90 percent of all carbon dioxide emissions.

In order to contain further climate change or contain it to the projected limits for the benefit of mankind, all future development need to be sustainable, and therefore it is required to end our reliance on fossil fuels and invest in alternative sources of energy that are clean, accessible, affordable, sustainable, and reliable.

The sustainable development takes into account the societal, environmental, and economic factors to ensure optimal balance while pursuing an enhanced quality of life. While sustainability is a long-term objective, sustainable development includes the various methods and strategies that can be effectively leveraged to achieve the goal of sustainability.

Renewable Energy qualifies as one of the foremost means to minimize the worst impacts of the climate crisis. Economic developments and technological advancements in renewables, such as carbon capture and storage, are directly impacting the strategies for sustainable development.

Keynote Speakers



Mr Rahul Wagh

Senior Engineering Manager,
Innovation, Research & Technology,
Baker Hughes.

Topic: Addressing Energy Transition through Technology Leadership

Decarbonization is large complex problem, mankind needs to solve for its own future generation and Flora Fauna for safe and healthy co-existence on the planet. The use of renewable energy sources to meet the ever-growing global energy demand, which is currently met through fossil fuels would help in lowering the emissions, this path towards the decarbonization is often referred as Energy Transition.

The solution steps for energy transition need to find the intersection of energy security, affordability, and sustainability. Balancing this Energy Trilemma needs multiple actions from different stakeholders; favorable policies from government, accessible financing from private and public sector financing institutions, and most importantly feasible & Scalable Innovative technology solutions evolved through collaborative efforts of academia, research agencies and private sector.

Wind and solar energy share are increasing in energy mix, but intermittency would be there forever, flexible energy storage and distribution systems would be key for sustainable energy transition. While sufficient storage capacity is developed, advanced and cost-effective carbon capture utilization and storage technology solutions are needed to collect the CO₂ emissions generated by fossil fuels until they fade from the energy mix. Green Hydrogen, biofuels, Small modular nuclear reactors are tracing their own torturous path to get relevant share in energy mix, courtesy their high \$/KW generation cost, or technology maturity level compared to hydrocarbons.

Keynote Speakers



Mr Umang Swaroop

Manager,
Siemens Energy

Topic: Heat Pump

A heat pump is a versatile and energy-efficient technology that facilitates the transfer of heat between a heat source and a heat sink. Operating on the principle of refrigeration, heat pumps can provide both heating and cooling functions for residential, commercial, and industrial applications. The core components of a heat pump include a compressor, condenser, expansion valve, and evaporator. The heat pump extracts heat from low grade energy heat source (air, water, or flue gas) and transfers it to the heat sink, raising the temperature. The efficiency of heat pumps is often measured by the coefficient of performance (COP), representing the ratio of

heat output to the energy input. Modern heat pump systems leverage advanced technologies such as variable-speed compressors, smart controls, and refrigerants with low environmental impact to enhance performance and sustainability. As the demand for sustainable heating and cooling solutions grows, heat pumps play a crucial role in reducing carbon emissions and promoting energy conservation in diverse climate conditions.

Keynote Speakers



Mr Selvaraji Muthu

Senior General Manager,
MAHLE Engine Components
India Pvt Ltd

Topic: MAHLE Advanced Products technologies for Carbon-neutral Powertrains and New Energy Vehicles

Carbon-neutral powertrain vehicles are important today because they play a crucial role in mitigating climate change and reducing air pollution. By emitting zero or minimal greenhouse gases during operation, such as carbon dioxide (CO₂) and other harmful gases (SO_x, NO_x, CO etc.), they help combat global warming and the associated impacts on the environment and human health. Carbon-neutral powertrain vehicles, such as electric cars or hydrogen fuel cell vehicles and Hydrogen combustion IC engine powered vehicles, also reduce dependence on fossil fuels, promoting energy independence and security. These solutions contribute to cleaner air quality, improving public health by reducing harmful emissions like nitrogen oxides (NO_x) and particulate matter (PM). Additionally, Carbon-neutral powertrain vehicles drive innovation, fostering the development of sustainable transportation solutions and supporting the transition to a more sustainable and resilient future.

- Brief on BS6.2 OBD2, CAFE2 norms and upcoming EU7 norm (and possibly BS7)
- Interim solutions to reduce CO₂ emission by using bio-fuel (Ethanol blended gasoline) and Hydrogen blended CNG.
- Various powertrain solutions to meet carbon-neutral mobility
- Brief on Fuel cell engine powertrain
- Detailed discussion on hydrogen Combustion IC engine and its performance comparison to fuel cell and battery powered electric vehicle.
- Optimized products for H₂ ICE.
- India roadmap on green hydrogen production and carbon neutral target of India.
- Summary for the session

Keynote Speakers



Dr Sushil S Ramdasi

Deputy Director,
In Charge –
Powertrain Design, ARAI

Topic: Challenges and Opportunities in Indigenization of E Mobility from an Indian Perspectives

In order to address present global warming and greenhouse gas effect, there is need to achieve CO₂ emissions much below than 100 g / km from present and future power plants. This is possible only when there will be reduction in fossil fuel consumption in the range of 25 - 40 % from present levels. Also, due to use of technology options required for meeting present emission norms in case of ICE based powertrains; cost of engine on serial production level is becoming very expensive. This has now given revolutionary thought of change in technology and not to upgrade present technology. Electrification is one of the attractive solutions in present conditions and technology options available. Electrification is of three-fold in nature. Use of present downsized diesel / gasoline engine technology in coalition with modern electric drive technology results in first level of electrification which is called as Hybrid Electric Powerplant. Battery Electric based Power plants will be the next level technology which will result in zero carbon footprint if electricity for charging of the batteries will be produced from renewables. Integrating Fuel Cell technology with electric motor drive system makes a platform for Zero Emissions which is a third level of electrification. Success of these alternate powertrains is a function of cost of final product on mass scale basis, flexibility during usage e.g availability of charging infrastructures, battery swapping and recycling technology etc in case of EV's and availability of Hydrogen in case of FCEV's. In order to achieve these parameters, indigenization of the electric drive systems and components will be going to play a vital role. Thus, while transforming from conventional to electrified powertrains there will be lots of challenges and opportunities to create a sustainable supply chain and eco system. Making of IM, PMSM, SRM, Power electronics, DC-DC converters, multilevel inverters, advanced chemistry batteries viz salt state and Sodium ion, PEM Fuel Cell stacks and Balance of Plant components, VCU, MCU, FCU, sensors and wiring harness, AMT, DCT etc. will fetch several avenues for business generation and skill sets creation.

Keynote Speakers



Mr Vipindas Othiyil

Program Director,
Bosch Global Software
Technologies Pvt Ltd, Coimbatore



Dr Balaji Srinivasan

Head of Engineering,
Bosch Global Software
Technologies Pvt Ltd, Coimbatore

Topic: Hydrogen based technology for stationary applications - SOFC

The climate changes that are becoming visible today are a challenge for the global community. Plus, strict emission norms and depletion of fossil fuels demand the need for new technologies. The stationary applications sector is one of the most important energy consumers. Harnessing the potential of renewable energy worldwide is currently being considered to find alternatives for obtaining energy by using technologies that offer maximum efficiency and minimum Pollution.

Hydrogen fuel cell technology is considered as a viable solution for future energy needs and to meet tighter emission targets. Hydrogen as a future fuel can create new business landscape and it can set stage for innovation.

Fuel cells are devices that generate electricity through electro chemical process and not through combustion. In Fuel cells Hydrogen and oxygen are combined to generate electricity. There are many types of fuel cell technology available today. PEMFC (Proton exchange membrane) and SOFC (Solid oxide fuel cell) are the important ones with matured technology. PEMFC is preferred solution for mobility application whereas SOFC is most suited for stationary power. SOFC produce clean, efficient, and reliable off-grid power to homes, businesses, telecommunications networks, utilities, and others. Stationary fuel cells are quiet and have very low emissions, so they can be installed nearly anywhere. These systems provide power on-site directly to customers, without the efficiency losses of long-range grid transmission.

Hydrogen can be directly used as a fuel or using reforming techniques it can be generated from Natural gas or biogas. SOFC needs higher temperature 700°C to 800°C to work efficiently. Individual fuel cells are stacked as one unit and multiple stack units are used for higher power demands. Fuel cell systems need a comprehensive balance of plant components (Like Compressors, heat exchangers, reformers, burners, catalytic converters, cooling systems), control units, batteries, and electrical systems.

Keynote Speakers



Dr. Sujit Sopan Barhate

Senior Chief Engineer and Head EV R&D,
CREAT UNO MINDA,
Pune, Maharashtra, India

Topic: Diagnosing Fuel Cells in Automotive Applications - Online, Non-invasive and Non-destructive

Global warming is a challenge for the world. Global warming is resulted due to greenhouse gases (GHG) emitted by various sectors worldwide. Carbon Dioxide (CO₂) is one of the major contributors to GHG. GHG traps heat and is hence the major reason for Global Warming. The transportation sector contributes 16.2% to the CO₂ emissions worldwide. 11.9% is due to the road transport. The emissions are caused by the energy which is used in the sector. 17% of the total energy is consumed by the transport sector in India. It results in 13% for CO₂ emissions. The transport sector emits 39% of NO_x and 4% of PM_{2.5} in India. Hence, reducing GHG emissions resulting from the transport sector is needed.

There are multiple ways the emissions can be reduced in the transport sector. The first attempt is done by improving efficiency and reducing emissions by having technical advances in the internal combustion engines (ICE). Indian regulations until Bharat VI have increased the efficiency of the ICE system and reduced emissions. However, this is not enough as the emissions need to be further reduced. So, various steps have been taken by automakers to reduce emissions. Alternate fuels that help reduce emissions are worked out and deployed. Alternate fuels like compressed natural gas (CNG), liquid natural gas (LNG), bio-diesel, ethanol blend, and hydrogen are being used. These fuels are better for emissions as compared to petrol and diesel. Diesel engines are discouraged in many states/cities of India. Few automakers have even discontinued building vehicles using diesel engines. Furthermore, to reduce emissions, hybrid vehicles are being made. The hybrid vehicle has both ICE and electric drivetrains. A relatively smaller ICE is used for peak load and to charge batteries. Since the ICE is smaller, it emits less than the ICE vehicles. Various hybrid vehicle architectures like, series, parallel, and plug-in-hybrid are available. Few hybrid architectures are used as a range extender for the electric drivetrain. Acceptance of hybrid vehicles is increasing. Strong hybrid vehicle sale has outshone the market by more than 3,100% as compared to last year (1,467 to 47,124 units) in India. Full battery electric vehicles (BEV) have been gaining acceptance and popularity in India for the last 5-7 years. There is no ICE in the BEVs hence, it does not emit GHG. BEV sales are increasing more than 130% year-on-year.

The auto industry is aiming to achieve 30% BEVs of the total vehicle population by 2030. However, BEVs are using the electricity from the grid to charge the batteries. However, more than 75% of energy is generated using fossil fuels. So, the industry is exploring ways to generate environmentally friendly energy. Hydrogen is considered as a fuel for the future. India has taken the lead in Green hydrogen generation. The hydrogen is generated by the electrolysis of water using electricity from renewable sources. It is an excellent energy carrier (142MJ/kg). It is a clean fuel as it emits zero GHG. Hydrogen can be used in vehicles in three ways. Hydrogen blended with CNG, hydrogen ICE, and fuel cell electric hybrid vehicles (FCEV). The ultimate solution for decarbonizing the transport sector is to use hydrogen in fuel cells to produce electricity. The generated electricity can be stored in batteries and directly used to drive the vehicle. These vehicles emit water vapor from the tailpipe.

The transport sector requires a fuel cell life of more than 5000 hours of continuous operation. The fuel cell performance degrades if faults are developed in the system. The common faults in the fuel cell are water flooding, reactant gas starvation, and high operating temperature. If the fault condition arises, the fuel cell performance degrades substantially. Prolonged exposure to the faults reduces the remaining useful life (RUL) of the fuel cell. So, detecting the fault condition and taking action to remove the fault condition is key to increasing RUL. However, if the vehicle applications the faults have to be continuously monitored without causing a downtime of the vehicle. Hence, there is a need for on-board and online diagnostics methods. These methods are non-destructive. As the fuel cells are in the vehicle, the diagnosis shall be performed using the minimum possible sensors. Hence, the methods have to be non-invasive. The session today focuses on mathematical models developed to fulfil the requirement of the fuel cell diagnosis in the vehicle. The models are electrical equivalent circuits, autoregression moving averages (ARMA), ratios, and fuzzy membership values. These models can be programmed in an electronic control unit (ECU) of the vehicle to monitor and diagnose the fuel cells. These models have proven better accuracy and precision over detailed physical models of the fuel cells.

Keynote Speakers



Mr Gaurav Kumar

R&D Manager,
Industrial Steam Turbines &
Auxiliaries, Siemens Energy

Topic: Compressed Air Energy Storage

The world is seeing phenomenal growth of green renewable power from wind and solar etc. By 2050 the renewable share of wind and solar in US power generation mix is expected to grow to 38 percent. Globally the wind and solar grid installations are outpacing the fossil fuels. Both these resources can deliver power with no fuel costs and zero emissions which is an ideal combination for electricity's Decarbonization. However both these resources share a big shortcoming. They depend on a key variant of weather – as in whether (and to what degree) the wind is blowing or the sun is shining. Additionally there is a requirement for a green storage solution also for this green energy. This storage solution should balance the generation variability of these renewable resources to optimize the base load by minimizing load swings and fluctuations. Without a cost effective storage solution it is virtually impossible for utilities to align the variability in renewable power generation with daily and seasonal fluctuations in demand.

CAES technology provides a solution which is capable of rapid start-up, high turn-down ratio and ramp rate, simultaneously operating in compression and expansion modes and starting in isolation. The focus of the technology is on - how the power-generation operators can use CAES technology for a reliable, cost-effective, and long-duration energy storage solution at grid scale.

- The CAES system has following main components - a compression train, storage unit and finally an expander train.
- CAES technology is advantageous over Lithium ion battery solutions in achieving sufficient storage duration to support high renewable penetration. The battery solutions are not well suited for energy storage duration level beyond ~ 4 hours. In addition battery system has life of ~8 years in comparison to CAES life of ~30 years.

Keynote Speakers



Mr Sayantan Paul

R & D Team Lead,
Siemens Energy

Topic: Carbon Capture Utilization and Storage and Green Hydrogen

Waste Heat Recovery (WHR) represents a significant opportunity for Industrial Processes to improve plant efficiency and reduce their carbon footprint. Often waste heat is of low temperature quality, and it can be difficult to efficiently utilize the quantity heat contained. As a part of Decarbonization initiative, industries are now looking for options to tap this lost heat into usable electrical energy. In these cases, the Organic Rankine Cycle-Technology (ORC) brings an additional benefit to raise the overall plant efficiency. The ORC unit utilizes this otherwise lost energy and converts it to usable power. The Organic Rankine Cycle is named after Scottish engineer and physics William John Macquorn Rankine (1820 – 1872). Instead of a conventional water-steam, the ORC system vaporizes an organic, high molecular mass fluid with a liquid-vapor phase change or boiling point occurring at lower temperatures than water-steam. The fluid allows ORC-cycle heat recovery from lower temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds etc. The low-temperature heat is converted into useful work, that can itself be converted into electricity. Waste heat recovery using ORC lowers CO₂ emissions through effective use of waste heat and reduce demand on primary energy because more power output can be achieved with same amount of fuel. It helps to improve the overall sustainability of the plant system. Against a conventional WHR solutions using Steam Rankine cycle, the ORC systems are simple and compact in design. Its ability to convert presently thrown away low grade waste heat to useful power at relatively lower capital investments makes it prospective for industrial WHR. With Decarbonization and carbon-neutral as core focus of industries, ORC promises to be the only carbon-neutral power generation cycle solution.

Keynote Speakers



Dr R Sethumadhavan

Energy Advisor, GSH Group,
Integrated Facilities Management,
Chennai

Topic: Decarbonization in Industries thro' Adoption of Energy Efficiency & Renewable Power

The G 20 is an intergovernmental forum of 19 major economies of the world including European Union that accounts for 72% of global energy consumption thereby necessitating aggressive decarbonisation activity in these countries to bring the CO₂ emission to manageable levels. India took over the presidency of G 20 in Dec 2022 and identified / earmarked Industrial Sector as one of major sectors for moving ahead with energy efficiency goals to curtail GHG emissions. This sector accounts for 12 % of total emission in India and thus the justification. A study by CII has revealed the scope of Energy Conservation in industries alone as 5 lakh Crores / annum with a job creation potential of 1 million / annum. India has targeted an ambitious task of 4% energy usage efficiency improvement year after year, aiming Carbon Neutrality by 2030 and Net Zero by 2070.

Focus therefore is needed on adoption of Energy Efficiency and Renewable Energy adoption in Industries in general and in Cement & Steel Sector in particular as these 2 sectors accounts for 12 % of overall CO₂ emission in India. Having said that, the Cement sectors that releases close to 300 million tons of CO₂ annually have embarked on the following interventions for curtailing CO₂ emissions:

- Fuel Switch (from coal to Biomass / Scrapped Tyres , MSW etc.,)
- Multi stage Heat Recovery in Kilns
- Performance improvements of the Process
- Carbon Sequestration (through Agro Forestry)

The first 3 activities – currently under implementation – are expected to cut the CO₂ emission levels by 20 – 25 % annually which is quite significant. However, the major impediment is the emission of CO₂ through the very process itself while manufacturing lime from limestone and the activity 4 is precisely aimed to address this emission. In effect, the Cement sector embarks on 3 pronged approach simultaneously, 1) Energy Efficiency 2) Renewable Green Power Usage and 3) Carbon Capture through greening the campus and expected to offer encouraging results.

In conclusion, it can be inferred that – India cement industries that have set benchmark on energy efficiency – has gone overboard to cut down CO₂ emission through adoption of latest technologies that are certain to yield results in immediate future.

Keynote Speakers



Mr K N Jayashankar

Project Lead,
ENERCON

Topic: Technology advancement in Wind turbine and Market need

World leaders have gathered in UAE as a part of COP28 to review Climate action for 2030 and net zero targets. Focus of the event is to establish mechanisms to achieve energy transition from fossil fuels towards renewable energy sources. Since the invention of windmills, engineers has always explored every possible way to enhance wind energy for power generation. From 1990 till date, wind turbines have considerably increased in size and nameplate capacity from kilowatt to multi-megawatt. As the demand for renewable energy surges, it is expected that technology is advancing continuously to meet ever increasing requirements of Availability, Levelized Cost of Electricity, Power electronics, regional specific design and operational requirements like noise and safety, grid requirements, design for transportation & manufacturing. In this session, an attempt is made to discuss technologies in onshore wind related to two longest and highest cost driven wind turbine blades and development of wind turbine towers. Extensive research is ongoing to optimize the design and develop innovative combinations to design aerodynamically efficient longer blades and taller towers. India is one of the top 3 countries in terms of installed fleet and is considered as one of the top 5 production hubs for wind turbine components, with still a great potential to synchronize with development of technologies.

Keynote Speakers



Dr Keerthivasan Rajamani

Assistant Professor,
University TWENTE, Netherlands

Topic: TCO₂ capture – Overview and insight

Much of the humankind's progress since the industrial revolution has been at the cost of environmental deterioration. One of the prime aspects is the CO₂ emission and its impact on global warming. In this presentation, an overview of different CO₂ capture technologies would be discussed in the context of post-combustion CO₂ capture and Direct Air Capture. We will leverage insights from thermodynamics and learn to make back-of-the-envelope calculations in determining the efficiency of any CO₂ capture plant. The presentation would end with a discussion on the expected trends in the future of CO₂ capture.

The logo for FLSMIDTH CEMENT, featuring the company name in white, bold, sans-serif capital letters on a dark blue rectangular background.

**FLSMIDTH
CEMENT**

THE CEMENT CHALLENGE OPPORTUNITY

Our climate is changing. Manmade global warming is causing increasingly severe weather events that impact billions of lives. Meanwhile, the population is growing. 75% of the infrastructure that will be needed in 2050 has not yet been built. Hospitals, roads, bridges, dams, offices, wind turbines – all require cement. Yet cement is a major contributor of the greenhouse gas emissions that cause climate change. How can the industry transition from being part of the problem to part of the solution?

This is the question that drives our pure play strategy for cement: Green 26. We're working with cement plants on ways to reduce carbon emissions, including through fossil fuel replacement and energy efficiency projects. Key product developments – such as the JETFLEX® multi-fuel burner, the FUELFLEX® pyrolizer, and the FEEDflex® feeder – have already enabled cement plants to reduce fossil fuel use to the absolute minimum and increase alternative fuels use up to 100%. Digital tools and digitally-enabled technologies also have a critical part to play in increasing process efficiency. Advanced control systems such as ECS/ProcessExpert® optimise

equipment operations and fuel and materials use to minimise energy consumption and further reduce emissions. We're also helping cement plants reduce the clinker content of cement by developing solutions for the use of lower-emission alternatives such as calcined clay.

We are refining and optimising processes across the flow sheet, developing proprietary technologies and forging partnerships that work towards decarbonisation. We believe that great headway can be made by simply running cement plants better, which is why we've expanded our service offerings to support plants to increase efficiency, productivity and sustainability. Of course, new technologies – such as carbon capture – are needed to achieve net zero cement, which is why we're also running pilot carbon capture projects to support the development of those systems and ensure the cement industry has the solutions required to meet its environmental goals. We're committed. We're ambitious. We're ready to go.

An aerial photograph of a cement plant. In the foreground, a tall, white, lattice-structured silo or tower stands prominently. The plant's various structures and conveyor systems are visible below. The background consists of rolling green hills under a clear sky.

PAVING THE WAY FOR THE GREEN TRANSITION



C.R.I. PUMPS
Pumping trust... Worldwide.

NATIONAL ENERGY CONSERVATION AWARD

C.R.I. HAS MADE HISTORY FOR THE 8TH TIME



Mr. G. SELVARAJ, Managing Director of C.R.I. Pumps and **Ms. SAHITHYA SOUNDARARAJAN**, Executive Director of C.R.I. Pumps received the NEC Award from the **Hon'ble President of India, Smt. DROUPADI MURMU**

- ☛ Over 2.1 million energy-efficient, star-rated pumpsets have been installed.
- ☛ 14,000 solar pumping systems and over 1,00,000 IoT-enabled smart pumpsets have been successfully commissioned.
- ☛ C.R.I. achieved a cumulative energy savings of 3,150 million units (kWh), thereby reducing 2.5 million tonnes of CO₂ emissions for our nation.
- ☛ Acquisitions in UK and Italy has catalysed C.R.I.'s global presence.
- ☛ Export Excellence Award 16 times • 9000+ products • Sold over 120 countries • 30000+ outlets.



PUMPS • MOTORS • PIPES • IoT DRIVES & CONTROLLERS • WIRES & CABLES • SOLAR

International certifications |       | ISO 9001 & ISO 14001

Toll free 1800 121 1243 | www.crigroups.com | Chatbot +91 95004 01115

☛ **Caters To Diverse Segments** ☛

**WATER & WASTE WATER | SOLAR | PROCESS INDUSTRIES | SEWAGE & EFFLUENT TREATMENT PLANTS |
HVAC | FIRE FIGHTING | METAL & MINING | FOOD & BEVERAGE | AGRICULTURE | RESIDENTIAL**

GCDI - 2023 Manuscripts





Leap Green Energy

We Partner Your Tomorrow

Largest partner for
Industries &
Commercial
Establishments
for their
Decarbonisation
Goals



Scenario of Solar Photovoltaic Water Pumping System

Ajay Kumar M

Centre for solar water pumping system, V4I Tech Bangalore IT, Saginville R&D Institute of Science and Technology, Chennai 605 062, Tamil Nadu, India
mkt121@gmail.com

Christopher S

Centre for solar water pumping system, V4I Tech Bangalore IT, Saginville R&D Institute of Science and Technology, Chennai 605 062, Tamil Nadu, India
drchristopher@saginville.com

Richa Parmar

National Institute of Solar Energy, Gurgaon-122 001, Haryana, India
richa.parmar@nise.ac.in

Chandhan Banerjee

National Institute of Solar Energy, Gurgaon-122 001, Haryana, India
chandhan.banerjee@nise.ac.in

Abstract

The lack of electricity and high diesel costs have an impact on pumping requirements of community water supply and irrigation especially in rural areas. Therefore, using solar energy for water pumping is a possible alternative to traditional electricity and diesel-based pumping systems. Photovoltaic (PV) technology is the foundation of solar water pumping, which transforms solar energy into electrical energy to power a DC or AC motor for driving water pumps. This review gives a glimpse of information on solar water pumping technology, and the research gaps for its wider adoption. The matching of characteristics between solar photovoltaic modules, controller, motor and pump is the great task to obtain optimum overall efficiency of solar pump efficiency.

Keywords: Photovoltaic, renewable energy, solar energy, solar pump, water pump efficiency

1. INTRODUCTION

Energy is crucial for continuous human development and for human life. There is a need for a secure and sustainable supply of energy for sustainability of modern societies. Now, energy has become an integral part of human life for almost every activity like domestic, transport, industrial, medical, etc. This will create an unsustainable situation in near future. Renewable energy resources such as solar, wind, biomass, water, and tidal energies are abundant, inexhaustible, and environmentally friendly. The Fig. 1 shows the power production potential in India as on July 2023 based on the renewable sources of energy, i.e. that solar energy has been improved to 71 GW [1]. Out of solar renewable source of energy solar contributes to 40%.



Figure 1: Renewable power potential in India

Figure 2 shows the average of Global Horizontal Irradiance (GHI) in India between the year 1999 to 2018 [2]. This gives an indication that, India can tap solar energy to a maximum extent.



Figure 2: Global Horizontal Irradiance (GHI)

Remarkable development in solar energy based technologies has been observed in last decades. The concerns related to cost and availability of fossil fuels, effects of climate change are the primary drivers behind the usage of these technologies. Figure 3 shows the state-wise installed capacity of solar energy in MW [1]. It was observed that, Rajasthan is the first province followed by Gujarat and Karnataka. Some is reflected in GHI contour plot (refer Fig. 2).

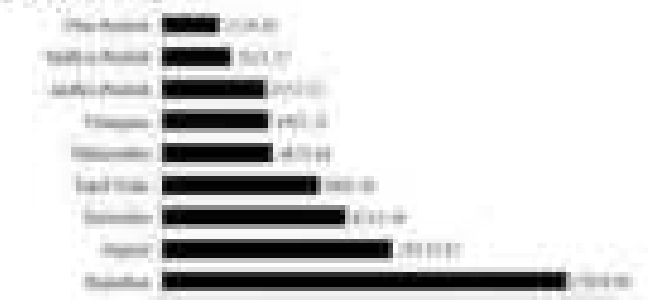


Figure 3: State-wise installed capacity of solar energy (MW)

Within India, there are different climates as shown in Table 1 [4]. It can be concluded that the performance of solar pumping systems will not be the same from one province to other provinces at particular day of operation.

Table 1 Climate zone across India

Climate	States
Hot and Dry	Rajasthan, Gujarat, Western Madhya Pradesh, Maharashtra
Warm and Humid	Kerala, Tamil Nadu, Western and Southern Orissa
Temperate	Madhya Pradesh
Cold	Western & Northern Ladakh
Mountain (Himalay)	Himachal Pradesh, Uttarakhand
Temperate	Uttar Pradesh, Jharkhand, Punjab, Bihar, Northeast India

II. SOLAR WATER PUMPING SYSTEM

Solar pump systems employ solar photovoltaic modules to convert irradiance into electricity, which is then used to power AC or DC motors for driving surface or submersible pumps. Solar PV modules develop DC, which is then converted to alternating current and voltage by a suitable solar pump controller (inverter) based on the amount of voltage required by the solar pump. Solar pump controller includes Maximum Power Point Tracking (MPPT) technology for maximum power output from solar PV modules, as well as overvoltage, under voltage, reverse polarity, and dry running protections. Figure 4 shows the schematic layout of solar water pumping.

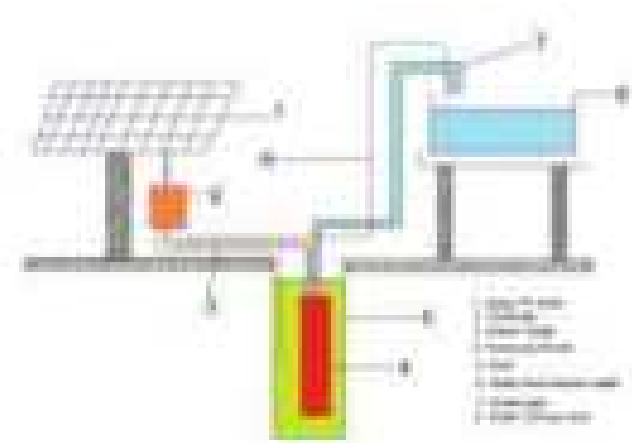


Figure 4: Schematic of solar water pumping system

Table 2 shows the classification of solar PV modules with efficiency [7]. It infers that still much more research is needed for enhancing the solar PV efficiency. The performance of solar pump varies with respect to irradiance and ambient temperature, thereby the module temperature plays a vital role in solar panel efficiency.

Table 2 Types of solar PV modules

Solar Cell Type	Efficiency	Pros	Cons
Monocrystalline Panel	20%	High efficiency rate and optimum for limited space	Expensive
Polycrystalline Panel	15%	Low price	Requires high temperatures for a life span & low power efficiency
Thin Film (amorphous silicon solar Panel)	5-6%	a. Reduces heat stress and over production of energy b. Very high performance and efficiency rate	More heat stress and lifespan
Concentrated Photovoltaic cell	40-45%		Solar water and cooling system needed

The solar charge controller regulates the flow of energy from the solar PV to the pump, ensuring that the power does not exceed the capacity of pump and working to reduce waste energy. In general there are two methods. The first one is Pulse Width Modulation (PWM). It is commonly used control technique that generates analog signals from digital devices such as microcontrollers. The second one is the MPPT, it is used with variable power source to maximum energy extraction as irradiation varies. As far as the motor is concerns there are two main types AC (induction and synchronous motors) & DC (shunt, separately excited, series, permanent magnet, and compound motors). But in recent days because of material and technological advancements, it is further classified into various categories.

A pump is a mechanical device that pumps water from one level to another level (mechanical energy into hydraulic energy). Pumping water from wells, lakes, rivers, and other sources to buildings, residences, and other structures is a typical usage in residential, commercial, and industrial contexts. Pumps are classified as shown in Fig. 4.

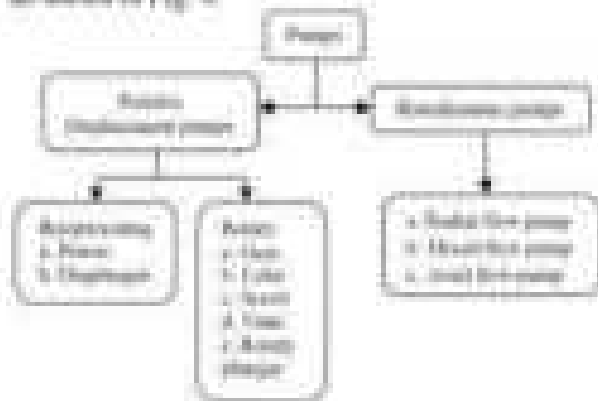


Figure 4: Classification of pump

The operation and maintenance of solar pumps should be fairly easy, since these units are typically located in remote places with limited professional labour [6]. The electrical array reconfiguration controller introduced a novel approach to optimize the performance of PV-powered water pumps by producing enough current to run the motor-pump at low irradiance levels, thereby providing a wide range of irradiance levels for operation and additional pumping hours [7]. An inductor and capacitor filter was introduced between PV array and inverter has been found instrumental in reducing the fluctuations thereby increasing the input supply to the inverter [8]. To maximize the conversion efficiency from the solar irradiance to the potential energy of water by taking into account of variations in the Total Dynamic Head (TDH) at a given installation was reported by Lopez et al. [9]. The load matching factor improves in solar irradiance increases, and it was feasible to attain a larger load matching by carefully selection of appropriate array and motor-pump subsystems [10].

The flow rate, output voltage-current and installation of a PV powered water pumping system to replace the existing conventional AC powered was tested and found that it was beneficial [11]. The Fuzzylogic Magnet Brushless (PMBL) DC motor has been shown to be effective in analyzing the drive systems of pump [12]. The simulation software programme, which employed the typical meteorological year weather data has been utilized in developing and predicting the long-term performance of a photovoltaic power system over any monthly or annual period [13]. Using MATLAB, the dynamic model of DC drive that is powered by a PV array through a boost converter were used to predict the performance of solar pumping system [14].

The SIMULINK programme is a simulation tool that is used to determine the response of a drive system by varying levels of light intensity [15]. The proposed model for determining the optimal PV pumping system for irrigation functions was found to have good results even for more complex conditions [16]. The power output of boost converter was measured at various duty cycles for solar irradiance and temperature for solar pumping system [17]. The theoretical potential of developing a solar pumping system taking into account the characteristics of TDH, economic feasibility, water requirements, and solar irradiation. This suggested system supplies more water than the required for the month [18].

III. Characteristics of pumping system

The Fig. 5 shows the general characteristics of centrifugal pump with total head, power & efficiency curve with respect to flow rate at one particular speed. To that system curve is plotted to understand the operating point of pump. Based on operating and best efficiency points, pump user has control to run the pump near the Best Efficiency Point (BEP).



Figure 5: Pump characteristics curve

The Fig. 6 gives the typical solar pump characteristics for different TDH conditions. Flow rate (Q) and water efficiency (η_w) are plotted with reference to solar power. Unlike pump performance characteristics the best efficiency area will not be shown, since it is plotted with respect to irradiance power. This plot gives the information how the solar pump will operate at any particular TDH.

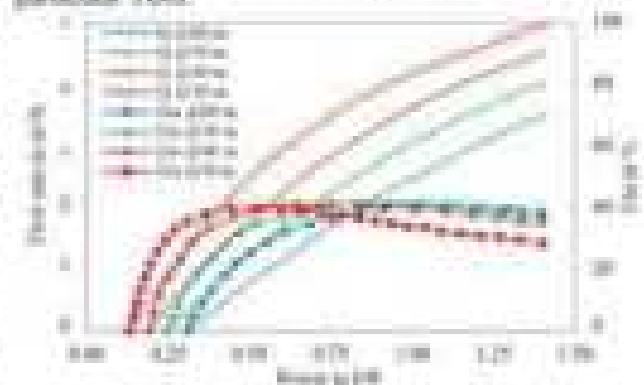


Figure 6: Solar pump characteristics curve

IV CONCLUSION

Solar based pumping system grows exponentially to meet the demand of irrigation purpose and so on. Hence it is necessary in certain some ways for better enhancement of overall system. The general pump characteristics will give the best efficiency point to operate the pump within the allowable range of operation. Whereas, the solar pump characteristics does not give those range for optimum running of pump. Hence it is desired to find the allowable range for operation of solar pump with reference to wire to wire efficiency, flow rate, and mechanical power corresponds to total dynamic head. Now a days, various technology enhancement are available to monitor the pump operation and to give appropriate signal for achieving the optimum efficiency. Using machine learning method, these problems will be solved and to match the characteristics of solar photovoltaic, controller, motor, and pump. The best way is to control the speed of pump through variable frequency drive.

Acknowledgement

The project funded (TAO2017-600087) by Science and Engineering Research Board (SERB), New Delhi (19016), India under the scheme of Teachers' Associationship for Research Excellence (TARE) in collaboration with National Institute of Solar Energy, Gurgaon, Haryana – 122 002, India.

REFERENCE

- [1] <https://mca.gov.in/the-ministry-physical-program> (accessed on 10th Sep 2023).
- [2] <https://solarpump.com/images-and-graphs/download/index> (accessed on 10th Sep 2023).
- [3] <https://www.mca.gov.in/physical-program> (accessed on 10th Sep 2023).
- [4] <https://www.solarpump.com/physical-program> (accessed on 10th Sep 2023).
- [5] <https://www.premach.co.uk/blog/2015/09/types-of-solar-pumps/> (accessed on 10th Sep 2023).
- [6] J.H. Salameh, F. Dagher, The effect of electrical array reconfiguration on the performance of a PV-powered volumetric Water pump, *IEEE Transactions on Energy Conversion*, 5 (1990) 650-658.
- [7] R. Liebenberg, J.H.R. Eekels, F.S. VanderMeulen, High efficiency, long life actuator for PV water application, 6 (1995) 1025-1032.
- [8] C.L. Poma Sengupta, Manoj Singh, H.P. Singh, S.S. Murthy, Hyperresonant in poligations on a permanent magnet brushless DC motor fed by PV array for water pumping system, proceedings of the 31st International energy conversion engineering conference, 1998.
- [9] S.A. Laport, J.D. VanWyk, P.N. Mhura, Low Models of Photovoltaic Water Pumping Systems, IEEE Africa, 9th African conference in Africa, 1998.
- [10] M. Khatib, J.C. Jorda, D.P. Kothari, Performance Analysis of a Directly Coupled Photovoltaic Water-Pumping System, *IEEE Trans. Energy Convers.*, Volume 14 (1999) 613-618.
- [11] Purnendu Chatterjee, A. Jais, Mayana, A model for optimal sizing of photovoltaic irrigation water pumping system, *Solar Energy*, 81 (2007) 904-916.
- [12] Dipank Paul, I. Deyan, Sumanth, PV powered solar well in Rajasthan- India, *IEEE International Conference on Industrial Technology*, 2012.
- [13] Tamer Laport, Kiro Abdel, Amr Armanat, Design and Simulation of Photovoltaic Water Pumping System, *International journal of engineering and Advanced Technology*, (2011) 161-164.
- [14] Harish Kulkarni, M.A.S. Lillians, Solar powered brushless DC motor drive for water pumping system, *IEEE International Conference on Power and Embedded Drive Circuits*, (2017).
- [15] Anandulu K. Thirum, Vidya R. Kallurkar, Effects of wind load and solar radiation on the performance of solar water pumping system, *Renewable Energy*, (2018) 910-917.
- [16] S. SenthilKumar, Chandrasekharan Rathi, R. Akshay, R. Anandhar, M. Kishore, G. Maganah, Solar powered water pumping systems for irrigation: A comprehensive review on developments and prospects towards a green energy approach, *Mineral water proceeding*, 11 (2020) 561-567.
- [17] A. Elhadi, Y. Marouadi, A. Gouliani, A. Rahel, Najib H. Champa, Migration to solar water pump system: Environmental and economic benefits and their optimization using genetic algorithm based MPPT, *Energy Reports*, (2022) 10113-10115.
- [18] A. Saravanan, M. Redha, S.T. Sathya, D. Anandharajan, Intelligent control system for BLDC motor driven solar water pumping system using Wave algorithm, *ICAEI* (2022), 302-308.

Small and Domestic Ammonia Cooling Systems for Energy and Sustainability of India

P. Virumachan

Department of Mechanical
Engineering, PSU College
of Technology, Coimbatore

P. Karthiga Devi

Department of Physics,
Government Arts
College, Coimbatore

T. Pragas

Department of Mechanical
Engineering, PSU College
of Technology, Coimbatore

P. Nishu Prakash

Department of Mechanical
Engineering, PSU College
of Technology, Coimbatore

Abstract

Preserving the environment should be everyone's first and greatest concern. Technology has caused the climate to change as a result of fast industrial development. As a result of climate change, people have had to rely on increasingly complex technologies to live comfortably. The devices presently require electrical energy, the majority of which is generated by thermal sources. The air conditioning and cooling industry is a fast-growing industry. Air conditioning systems are expected to reach 25.4 million units in 2030, using more than 7300 TWh globally. The cooling systems predominantly use HCFC and HFC-based refrigerants, both of which have Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) concerns (ODP). When compared to natural refrigerants, the Coefficient of Performance for systems using ODP and GWP refrigerants is also moderate. Using a natural refrigerant like "Ammonia," which has zero ODP and 0% GWP, will reduce energy consumption by 10% TWh and 1000 TWh, respectively, when compared to systems using R134a and R410F. In comparison to R134a and R410 systems, ammonia systems will lower power generation by 1346.9 and 24% 2 TWh, respectively, and CO₂ generation through thermal plants by 25 and 40% despite the fact that ammonia gas is utilized in commercial systems. If it is a toxic and flammable gas that should be employed with safety measures when used in ammonia applications.

Keywords: Ammonia Refrigeration, Air conditioning, Cooling systems, CO₂ emissions, Energy, Electrical power generation

INTRODUCTION

Climate change has become an unavoidable phenomenon that necessitates the preservation of sustainable conditions. It also causes Mother Nature forces the world to endure the most adverse conditions. Presumably, sustainable people have become more civilized and advanced. Life progress has brought new machines and systems into people's living environments. These machines

and systems, in turn, need energy, usually electrical energy or work. As a result, from 2000 to 2018, energy generation increased by 3.6 percent per annum, generating more than 25000 TWh. Coal and gas-fired electricity generation account for 38% of overall energy generation [1]. When conventional fossil fuels are used to generate electricity, CO₂ emissions are produced, which contribute to global warming and have a negative impact on the atmosphere and environment. This produces a lot of hardship for the people in living [2]. Global CO₂ emissions are increasing by 3 percentage point per year, with about 1 billion tonnes of CO₂ released into the atmosphere every year. According to the International Energy Agency (IEA), fossil fuel emissions totaled more than 16000MT CO₂ in the year 2017. The amount of CO₂ emitted varies from region to region, regardless of the population[3]. North America, Oceania, Europe, and Latin America, which account for 8% of the global population, generate 18% of total emissions. Asia, which accounts for 60% of the global population, emits 40%, and African nations, which account for 16% of the global population, emits only 4% of total emissions [3]. This is because people in developing countries live more affluent lives using more gadgets. The per capita energy intake of different countries demonstrates this. The most developed countries, such as those in North America, the European Union, and the Middle East, have higher per capita energy consumption, with more than 10000 kWh per annum, while the developing countries have lower per capita energy consumption [4], [5]. Sophisticated people's lifestyles lead to CO₂ emissions through their day-to-day habits. The COPUCC, through its Kyoto Protocol, set a target for developing countries to reduce CO₂ emissions by 7% below 1990 levels, and in its subsequent Paris Agreement of 2015, adopted a goal to keep global mean surface temperature rise below 2°C above preindustrial levels[6], [7]. As a result of the universal agreement, member countries agreed with

restrictions to reduce pollution by lowering fossil fuel power generation and promoting renewable energy generation. The automotive sector was mandated to produce engines with low emission norms. The industries which are contributing to the pollution were asked to control and minimize its share share. In this context, the air conditioning and refrigeration industries, which commonly used synthetic CFC refrigerants, are a substantial contributor to GWP and GHG emissions. It was observed that the Chlorine and Fluorine atoms when leaked or discharged into the atmosphere, they deplete ozone, causing global warming. According to the Montreal Protocol, countries must reduce their use of CFC chemicals, which would result in a 0.5°C increase in global warming by the year 2100 [8]. Also, the systems operating with CFC have moderate energy efficiency leads indirectly to high emissions of CO₂. This review investigates the feasibility of replacing synthetic refrigerants with natural refrigerants (R210), which would reduce GWP and GWP while improving energy efficiency and lowering CO₂ emissions.

Air conditioners and Refrigerants

The rise in the living standard of people due to economic growth, along with the increase in population and extreme heatwaves have increased the demand for air conditioners. Campbell et al had stated that penetration of air condition systems in the US and Europe is more than 90 percentage, 80 percentage in Japan and Korea, 60 percentage in China, and about 10 percentage in India, Brazil, Mexico, and Indonesia[9]. The global air conditioning market grew by 10 percent in 2016-2019[10]. The worldwide air conditioners sales are forecasted to reach over 25.4 million by 2024[11]. In the Indian context, the growth is expected to be 18 percentage annually. Air conditioner systems in many countries are mainly used to cool the confined space as the temperature in the summer varies from 33 to 47. A theoretical refrigerant is circulated through copper coils to provide the required comfort condition at the confined space. Currently, R22 and R410, and R32 are the refrigerants used in these systems. R410 and R32 are considered as a substitute for ozone-depleting (OD) chlorofluorocarbons [12].

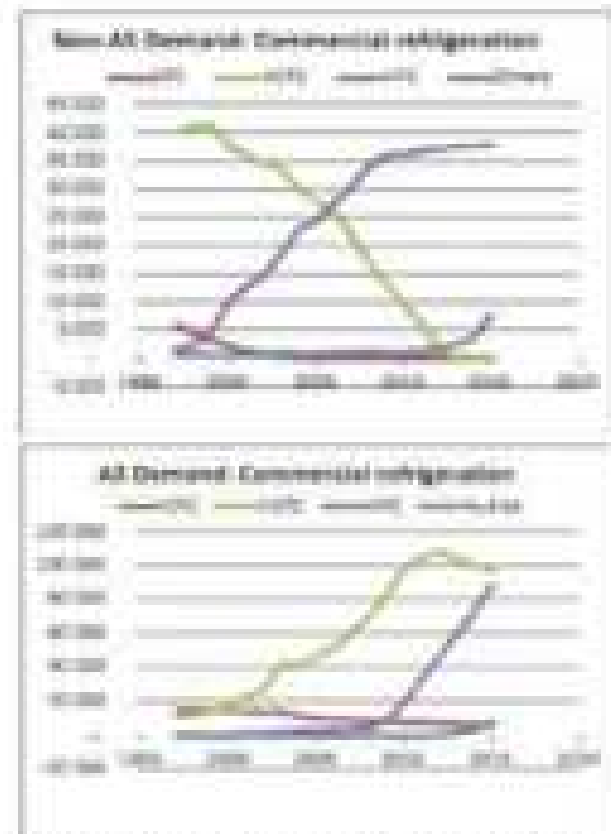


Figure 1 Demand of Refrigerants in Non - article 5 and article 5 countries according to UNEP TEAP 2012 report

The UNEP report 2019 illustrates the state and usage of various refrigerants. The UNEP classifies the developing and underdeveloped countries globally as Article 5 countries and the developed countries as non-Article 5 countries and stipulates different timelines to phase ODPs. According to Figure 1, the non-article 5 countries will reduce and phase out the HCFC refrigerants by 2015 and will supplement systems that use HFC. On the other hand, the demand for systems operating HFC will increase in the article 5 countries due to lack of technology and high cost. The number of units in these countries will exceed one million tons of refrigeration [12]. The demand for the HFC-based cooling system has reached 90 percent of the total demand worldwide after 2015 [13]. Overall HFC emissions from the cooling systems are growing at a rate of 3 percentage per year and the annual rise in emissions is projected to be 7.19% of global CO₂ emissions by 2050. The magnitude of radiative forcing by ozone-depleting substance (HFC) is 0.32W/m² and its alternative HFC was 0.12W/m² in 2010 and tends to grow to 0.40 W/m² in 2050. The Intergovernmental Panel on Climate Change

(IPCC) had stated that due to the above refrigerants the CO₂ emission had increased from 14 percent as of 2000 to 27 percent by 2000 [12].

Table 1 provides information about the ozone depletion and global warming potential of various refrigerants used currently. The substitute refrigerants have a lower GWP but have a very high ODP. They also have a very long time to degradation. Whereas, the natural compressed ammonia has zero ODP and zero GWP [14], [15]. In recent years, the use of HFCs as ODS replacements have increased by 10-15% a year globally [16]. The increased use of HFCs is a direct consequence of the Montreal Protocol's intention and activities, and therefore, an unintended negative impact of these actions can be seen as the contribution of the HFC to climate change. The increase in long-term HFCs will result in the benefits of the Montreal Protocol being reduced or completely lost [9].

Table 1. Refrigerant Properties

Refrigerant	Type	ODP	GWP	Atmospheric lifetime (years)
R12	CFC	0.9	1000	102
R22	HCFC	0.06	1700	11.3
R134a	HFC	0	1300	14
R407C	HFC blend	0	1610	36
R410A	HFC blend	0	1900	38
Ammonia (R717)	Natural compound	0	0	<1
Propane (R290)	HC	0	3	<1
R1234yf	HFC unsaturated	0	0	Very low
R1234ze	HFC unsaturated	0	0	Very low

Energy Input

The energy efficiency of all machines absorbing power is a major concern. These machines have to consume as minimal power as possible to achieve the desired effect. The energy efficiency of the refrigeration cycle is referred to as the Coefficient of performance (COP). The COP is the ratio of the refrigeration effect to the power input to the compressor. The heat absorbed in the evaporator is the refrigeration effect. The refrigeration systems COP ranges

from 1 to 8. Many factors are associated with achieving higher COP, and an important factor is the refrigerant used and its thermal properties. Many refrigerants have been developed over the years to achieve the best performance. Each refrigerant will have its own set of advantages and disadvantages. Lower COP systems will absorb more energy for the same cooling effect. Today, all the air conditioning systems use electrical energy to compress the refrigerant. The global electrical energy consumption for space cooling by air conditioners is approximately 1200 TWh in 2016 and is expected to increase to 7700 TWh in 2050, representing a 546percent increase in consumption [19]. At the generating stations, 1.5 kWh of power is to be produced for every 1 kWh of power consumed by the air conditioners. Thermal energy accounts for nearly 56 percent of all electricity generated in India [10]. These thermal power plants emit 0.99 kg CO₂/kWh of electricity generated [17], [18]. As a result, CO₂ emissions from air conditioners were 2377 ± 101.7 tonnes/kg CO₂ in 2014 and are expected to rise to 7623 ± 101.2 tonnes/kg CO₂ by 2050 globally [8]. The CO₂ emissions from air conditioners cannot be eliminated but can be reduced to a certain extent by improving the system's operating performance. Many countries have begun to implement various methods to increase the energy efficiency of room air conditioners. Since 2005, appliances in India have been labelled with energy stars from one star to five. Appliances with one star will have a low energy efficiency ratio, while those with five stars will have the highest ratio. Additionally, the efficiency values are increased regularly, as shown in table 2. This method enables the most efficient use of electrical power for electrically powered home appliances. If an air conditioning system can operate above these minimum ratings, it will be more beneficial in terms of lowering CO₂ emissions.

Table 1 Energy Efficiency ratio (Watt/Watt) as EER [16]

Star level	Jan-2009 to Dec-2011	Jan-2012 to Dec-2013	Jan-2014 to Dec-2016	Jan-2016 to Dec-2017	Jan-2018 to Dec-2020	Jan-2020 to Dec-2024
1 Star	2.5 – 2.69	2.5 – 2.69	2.7 – 2.89	2.7 – 2.89	3.1 – 3.29	3.3 – 3.49
2 Star	2.7 – 2.89	2.7 – 2.89	2.9 – 3.09	2.9 – 3.09	3.3 – 3.49	3.5 – 3.79
3 Star	3.1 – 3.29	3.1 – 3.29	3.4 – 3.59	3.4 – 3.59	3.7 – 3.89	3.9 – 4.19
4 Star	3.8 – 3.99	3.8 – 3.99	4.1 – 4.29	4.1 – 4.29	4.5 – 4.69	4.7 – 4.89
5 Star	4.3	4.3	4.5	4.5	4.7	4.8

A detailed study is carried out in this analysis for the reduction of energy consumption when an alternative natural refrigerant is used and its impact on reduction in the carbon emission and global warming for a sustainable environment.

Air conditioning Systems

Figure 2 describes a layout of an air conditioning system, the system has an air filter, sensible cooling and heating coils, a humidification chamber, filters, and a blower apart from compressor, condenser and throttle valve on the outdoor side. According to the Indian environment, the air is treated for cooling and dehumidification only.

Figure 3 illustrates the working of the refrigeration cycle used to provide the required cooling effect. The major working and power absorbing element in the cycle is the compressor. The performance of the total system is defined by EER or COP. The COP of the system is given by equation 1 and thermodynamically computed from the P-H chart shown in figure 4:

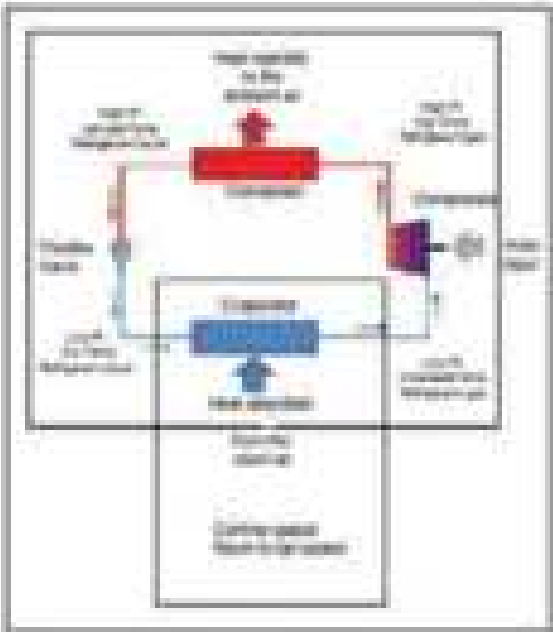


Figure 3 Refrigeration cycle

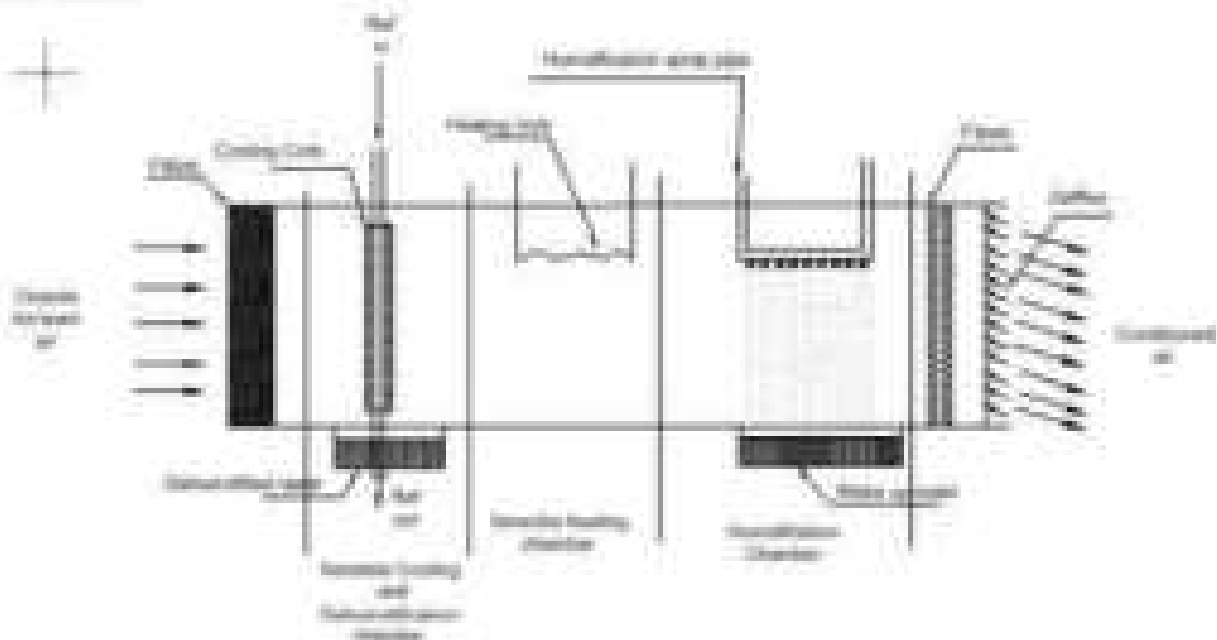


Figure 2 Schematic layout of an air conditioning system

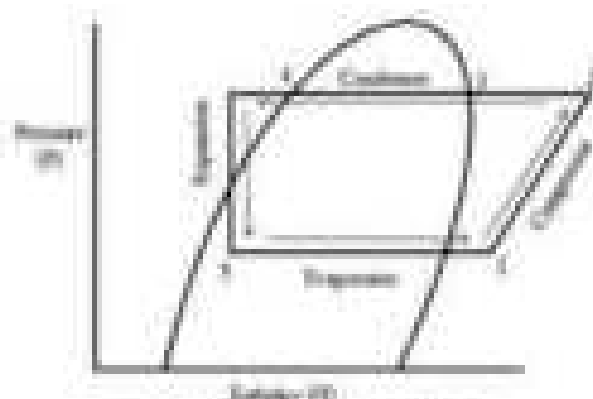


Figure 4 P-H Plot of a refrigeration cycle

$$COP = \frac{Q_{in}}{W_{in}} \quad (1)$$

From the P-H plot (Figure 4), it is observed that for the high latent heat of the refrigerant at lower pressure and with minimum compressor work, the Cop of the systems increases. The COP of the refrigeration system varies from 1 to 4 normally. To get the best performance many refrigerants were developed over the decades. Each refrigerant has its pros and cons.

The properties of the refrigerant playing a major role in achieving higher COP are:

- High latent heat of vaporization
- High critical gas density
- Positive but not excessive pressures at evaporating and condensing conditions
- Critical temperature and triple point well outside the working range
- Chemically stable, compatible with construction materials, and miscible with lubricants
- Non-toxic, non-corrosive, and non-flammable
- High dielectric strength
- Zero-GWP
- Zero-GWP
- Low cost

The HFC-based refrigerants with high COP and GWP are banned completely, to be phased out by 2020 and it is to be replaced with HFC-based refrigerants in the new systems. However, air conditioning systems older than 10 years have R22, which is to be taken care of. The HFC even though have zero GWP has a very high GWP. Therefore a refrigerant that does not spoil the atmosphere and the environment is the need of the hour. Natural refrigerants

such as ammonia and carbon-dioxide are the best alternatives. In particular, ammonia is the best substitute for HFC.

Ammonia as the refrigerant for air conditioning systems

Ammonia is a natural refrigerant that has been used for many years in a variety of applications due to its high thermal efficiency and low cost. Ammonia is an environmentally friendly gas and has zero GWP and ODP [20]. Ammonia refrigerant is presently used in industrial and commercial refrigeration, food preservation, indirect space conditioning, heat pumps, and other applications. Ammonia is emerging as one of the primary natural refrigerants of choice alternative to the CFCs. It has a high latent heat of vaporization eight times higher than R-12 and six times higher than R-134a. These characteristics result in a highly energy-efficient cycle with ammonia as the refrigerant with minimal environmental impact. New technologies leading to low and reduced ammonia charge designs are being developed. The application of these new low charge systems and packages creates an opportunity to use ammonia in a broad range of new industrial, commercial and indirect space conditioning applications that would not have been considered with traditional designs.

Already, ammonia-based refrigeration systems are used in thermal storage systems, HVAC chillers, process cooling, air conditioning, winter sports, district cooling systems, heat pump systems, supermarkets, convenience stores, large heat pump installations, and supermarkets, as well as in several high-profile projects, including the International Space Station and Phoenix II [21].

Since ammonia has multidimensional benefits, an evaluation is carried out for energy savings and other potential benefits in comparison with currently used refrigerants such as R22, R-134a, and R410a.

The evaluation criteria are maintained common for all the refrigerants and the system is to cool a confined space to 23° C from an ambient condition of 42°C typical summer condition in India. The capacity of the system is 1TR (3.5 kW) and 100 percent of air is recirculated. The operating condenser and evaporative pressures of the refrigerants considered are given in Table 3.

Table 3 Operating pressure of different refrigerants

Series	R22	R134a	R404a	R717
Condenser Pressure in bar	19.42	11.17	98.9	2.47
Evaporator Pressure in bar	4.36	2.52	8.96	11.07

The cycle diagram is plotted in the Pressure-Enthalpy plot (Figure 5) the properties at various state points are tabulated in table 4. State point 1 is considered as the inlet to the compressor which is dry saturated condition. Point 2 is the exit from the compressor and entry to the condenser, process 1-2 is considered as isentropic compression, the refrigerant as a superheated vapor enters the condenser. The heat rejection to the ambient air in the condenser is by a constant pressure process, the maximum reduction in temperature obtained is limited to 30°C as a maximum of 40°C is maintained between the inner and outer fluids. At point 3 the refrigerant exits from the condenser as saturated liquid and enters the throttling valve. During the throttling process, pressure is reduced and the refrigerant enters the evaporator at the low condition of point 4. The refrigerant flows through the evaporator coils absorbing the heat from the conditioned space thereby cooling the space.

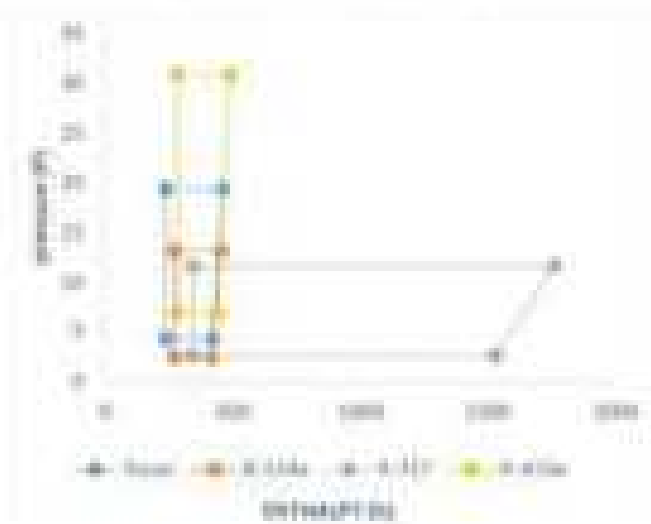


Figure 5 Pressure-Enthalpy of various refrigerants working in vapor compression cycle

Table 4 Properties of refrigerant at various state points

REFRIGERANT	R22	R22	R134a	R134a	R717
STATE POINT	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
Specific heat	kJ/kg	1.145	1.105	1.04	0.977
Density	kg/m ³	1207	1194	1197	1197
Pressure	bar	19.42	11.17	98.9	2.47
P ₁	bar	19.42	11.17	98.9	2.47
P ₂	bar	19.42	11.17	98.9	2.47
P ₃	bar	19.42	11.17	98.9	2.47
P ₄	bar	4.36	2.52	8.96	11.07
Temperature	°C	55	55	55	55
T ₁	°C	55	55	55	55
T ₂	°C	55	55	55	55
T ₃	°C	55	55	55	55
T ₄	°C	55	55	55	55
Enthalpy	kJ/kg	417.13	417.13	417.13	417.13
h ₁	kJ/kg	417.13	417.13	417.13	417.13
h ₂	kJ/kg	417.13	417.13	417.13	417.13
h ₃	kJ/kg	417.13	417.13	417.13	417.13
h ₄	kJ/kg	417.13	417.13	417.13	417.13
Enthalpy	kJ/kg	417.13	417.13	417.13	417.13
h ₁	kJ/kg	417.13	417.13	417.13	417.13
h ₂	kJ/kg	417.13	417.13	417.13	417.13
h ₃	kJ/kg	417.13	417.13	417.13	417.13
h ₄	kJ/kg	417.13	417.13	417.13	417.13
Specific work	kJ/kg	10.17	10.17	10.17	10.17
Mass of refrigerant	kg	0.02214	0.02214	0.02214	0.02214
work W	kJ	0.2214	0.2214	0.2214	0.2214
Q ₁	kJ	0.2214	0.2214	0.2214	0.2214

The coefficient of performance, Mass of refrigerant required, and the power consumption for the cooling load of 1 Ton (3.5 kW) are calculated using equations 1, 2, and 3 respectively, and the values are tabulated in table 4.

$$\text{Mass}_{\text{refrigerant}} = \frac{3.5 \text{ kW}}{h_1 - h_4} \quad \text{kg/s} \quad (1)$$

$$\text{P.W} = \text{Mass} \times (h_2 - h_1) \quad \text{kJ/s} \quad (2)$$

Results and discussion

The R22 (HCFC) has an evaporator and condenser pressure of 4.36 and 19.42 bar for the saturated condition. The refrigeration effect produced is 157.56 kJ/kg and the energy required to compress the refrigerant is 19.17 kJ/kg, with a COP of 8.22. The R134a is the best alternative for HCFC refrigerants and is suitable for small applications. The evaporator and condenser pressures are 2.52 and 11.17

bar, which is lower than R22. R134a has a refrigeration effect of 145.33 kJ/kg, compressor work of 77.88 kJ/kg, and COP as 1.76. The R410a, which is preferred for commercial applications has the highest condenser and evaporator pressure of 6.98 and 31.8 bar. R410a produces a refrigeration effect of 108 kJ/kg and requires a 90 kJ/kg of compressor work to operate with a COP of 1.2. The natural refrigerant R717 (ammonia) has the lowest operating pressure as 2.67 and 11.67 bar for condenser and evaporator, has the highest refrigeration effect of 1185 kJ/kg for the compressor work of 234.13 kJ, it operates with a COP of 5.064.

The R22 is an azeotropic gas that has a lower pressure ratio and has low compressor work per kg of gas but has a very high GWP and ODP, which makes them not suitable for use. The R134a has low pressure ratio but has a lower latent heat of vaporization due to which its COP is lower than R22 and does not have ODP but has a high GWP. The R410a has a very high-pressure ratio, low latent heat of vaporization, and COP. The high-pressure ratio leads to increased cost of equipment and the refrigerant has high GWP, which is to be stopped from usage.

The ammonia has a comparatively high theoretical COP among the four refrigerants, its pressure ratio is also lower than the other refrigerants. But the work required to compress per kg of refrigerant is four hundred percent higher than the currently used refrigerants. Since the temperature after throttling is minus 17°C, much lower than other refrigerants, reduces the mass of refrigerant required to circulate in the refrigeration loop. The reduction of mass by 90 percent reduces the compressor work required for 1 TR to 0.69 kW, whereas the work required for R134a and R410a is 0.92 kW and 1.18 kW.

Energy savings and reduction in CO₂

It is forecasted that in 2050 the cooling refrigeration systems will be consuming 778TCWh globally[11]. An analysis is carried out to estimate the power saving and reduction in CO₂ of all the cooling systems which would be operating with R134a Case I and R410a case II are replaced with R717 and are given in Figure 6-10.

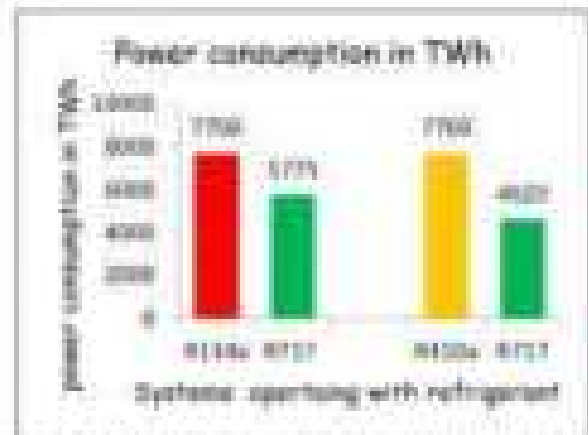


Figure 6 Power consumption comparisons between refrigerants

Figure 6 shows the energy requirement for cooling refrigeration systems of R134a, R410a, and if replaced with ammonia. In comparison to R134a and R410a, operating the systems with ammonia reduces energy usage by 1920 TWh and 3080 TWh, respectively. The energy thus minimized will be savings at the user end.

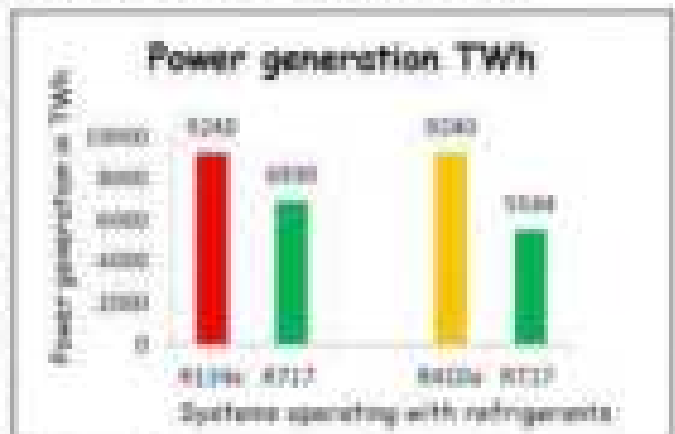


Figure 7 Power to be generated for cooling systems

For every 1 TWh of power to be supplied to the customer, the generation stations have to generate 1.25 TWh to account for the transmission and other losses [14]. Thus, according to the forecast, if 7760 TWh of power is required at the user end, 9240 TWh of power is to be generated at power stations. For the same time of refrigeration cooling if ammonia is used instead of R134a, 6780 TWh of power, if produced, will be sufficient and in the case of R410 replaced by ammonia 5540 TWh of power will satisfy the need. Ammonia systems can minimize and reduce the load on power stations by 25% and 40% respectively for R134a and R410a.

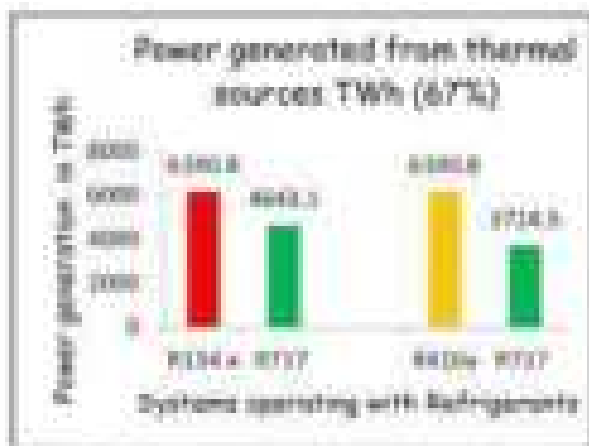


Figure 8 Power produced from thermal sources

According to the International Energy Agency report, the 67 percent of total power produced globally is through combustible fuels. These fuels when combusted will produce CO₂ emissions. Figure 8 gives the details about the share of energy consumed by refrigeration systems that are produced from thermal sources of power generation. Ammonia refrigeration cooling system may reduce the power generation to extent of 1344.8 and 2426.3TWh if replaced for R134a and R410a. The total power generation by the National Thermal Power Corporation (NTPC) plants of India for the period of 2020-2021 is about 2980 MWh [22]. Many of the thermal plants can be completely shut down due to the energy saved by ammonia refrigeration system as can be the power generated from thermal sources can be utilized for high production applications.

Chakraborty et al. had experimentally found that the average CO₂ emissions from various thermal power plants is about 0.946kg /kWh. Similarly, Mittal et al. had estimated the emissions from thermal power plants are in the range of 0.91 to 0.95 kg /kWh in India. Indian thermal plants are monitored periodically and operate with the best standards globally [23]. Hence the global CO₂ emissions from thermal plants can be considered regarding Indian emissions standards. By the Kyoto agreement, 190 member countries had agreed to reduce 50 billion metric tons of carbon dioxide equivalent emissions by 2050 [19]. CO₂ emissions from thermal power plants cannot be stopped but can be reduced if the electrical power generation is reduced. Figure 8 gives the savings in power utilization based on ammonia refrigeration.

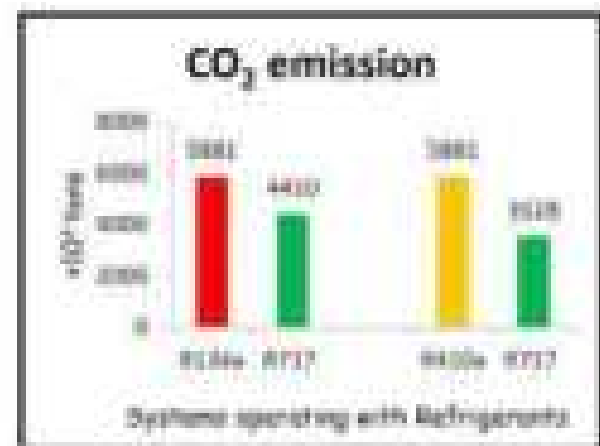


Figure 9 CO₂ production for different refrigerants based on energy consumption

Figure 9 describes the emission of CO₂ due to the energy generation from thermal power plants for the power required for cooling systems operating with R134a, R410a, and ammonia refrigerants by 2050. It is evident from the above that power generation CO₂ also reduces to 25 per cent and 40 percent when altered with ammonia. The CO₂ emission from one application sector is so substantial, which can be controlled and contained if proper action is taken.

Ammonia and its drawbacks

The main problem with ammonia is its toxicity. The U.S. Public Health Service's Agency for Toxic Substances and Disease Registry (ATSDR), as published in the IARC Ammonia Data Book, shows the effects of various concentrations of ammonia.

Table 6 Effects of various concentrations of ammonia

Concentration	Effect
1 ppm	Eye irritation, irritation and severe irritation (highly irritant)
10 ppm	Irritation
35 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
50 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
100 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
200 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
300 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
400 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
500 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
600 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
700 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
800 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
900 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)
1000 ppm	Severe eye irritation, irritation and severe irritation (highly irritant)

The National Institute for Occupational Safety and Health (NIOSH), in its 2007 Pocket Guide², has set the Immediate Danger to Life or Health (IDLH) level, the level at which an individual could be exposed for 30 minutes without a respirator and not experience any lasting health effects, at 300 parts per million. The purpose of IDLH is to establish when the maximum level of respiratory protection is required by OSHA regulations. Ammonia's sharp,

- [12] "Global Commercial AC Market Sales to Cross 21.4 Million Units by 2025: F&B Intelligence," F&B Intelligence, Sep. 21, 2020, <https://www.prnewswire.com/news-releases/global-commercial-ac-market-sales-to-cross-21-4-million-units-by-2025-foi-intelligence-301114467.html>. [Accessed Mar. 18, 2022].
- [13] "Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer: Fourteenth volume (2020)," 2022.
- [14] G. J. M. Velthuis et al., "Preserving Montreal protocol climate benefits by limiting HFCs," *Nature*, vol. 335, no. 5971, American Association for the Advancement of Science, pp. 922–923, Feb. 24, 2012. DOI: 10.1038/nature11644.
- [15] Roger Legg, *Air Conditioning System Design: Batterworths Handbook*, 2017. DOI: <https://doi.org/10.1016/C2015-0-04598-1>.
- [16] M. Mehranq, S. Jayang, and C. Maroufhaoui, "Environment-friendly alternatives to halogenated refrigerants-A review," *International Journal of Greenhouse Gas Control*, vol. 3, no. 1, pp. 108–119, Feb. 2009, DOI: 10.1016/j.ijggc.2008.07.005.
- [17] "CFCs Annual Report (2019-2020)," Oct. 2019. [Accessed Mar. 17, 2022]. [Online]. Available: <https://extension.cfaibhouston.org/wp-content/uploads/2020/04/2019-2020-report%20cfc%20annual%202020%20146.pdf&ecl=10466754&ecl=10466754>.
- [18] "Carbon emissions from the power sector in 2021-2022," Jan. 20, 2019, <https://extension.cfaibhouston.org/wp-content/uploads/2020/04/2019-2020-report%20cfc%20annual%202020%20146.pdf&ecl=10466754&ecl=10466754>. [Accessed Mar. 17, 2022].
- [19] M. L. Shrivastava, C. Sharma, and R. Singh, "Emissions of Greenhouse from Coal-Fired Thermal Power Plants in India," 2012. [Online]. Available: <https://www.researchgate.net/publication/314444444>.
- [20] PRODUCT MANUAL FOR ROOM AIR CONDITIONERS - PART 2: SPLIT AIR CONDITIONERS ACCORDING TO IS 1301 (PART 2), 2019, India: Bureau of Indian Standards, 2020. [Accessed Mar. 17, 2022]. [Online]. Available: <https://extension.cfaibhouston.org/wp-content/uploads/2020/04/2019-2020-report%20cfc%20annual%202020%20146.pdf&ecl=10466754&ecl=10466754>.
- [21] D. Ratz et al., "Ammonia as a Refrigerant," 2017. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0140670117300000>.
- [22] A. Farren, "Refrigeration with ammonia," *International Journal of Refrigeration*, vol. 11, no. 4, pp. 549–551, Jan. 2008. DOI: 10.1016/j.jrefrig.2007.11.011.
- [23] N. Chakraborty et al., "Measurement of CO₂, CH₄, N₂O, and NO emissions from coal-fired thermal power plants in India," *Atmospheric Environment*, vol. 42, no. 6, pp. 1073–1082, 2008. DOI: 10.1016/j.atmosenv.2007.10.074.
- [24] "Recent International Developments under the Montreal Protocol," U.S. Environmental Protection Agency, 2004. <https://www.epa.gov/stratospheric-substances/recent-international-developments-under-montreal-protocol>. [Accessed Mar. 17, 2022].

Effect of cross-sectional geometry in flow behaviour: A steady state computational study

Vijet Kumar
Vinayathas

Research Scholar,
Department of Automobile
Engineering,
PSG College of
Technology,
Coimbatore, India
Email:
vijaykumarvinayathas@gmail.com

Karthikeyan
Palanisamy

Professor,
Department of
Automobile
Engineering,
PSG College of
Technology,
Coimbatore, India
Email:
kprasad@psgtech.ac.in

Drashtkumar Pansodkar

Research Scholar,
Department of
Automobile Engineering,
PSG College of
Technology,
Coimbatore, India
Email:
drashtkumar.pansodkar@gmail.com

Rajeeviraj Karthikeyan

Research Scholar,
Department of Automobile
Engineering,
PSG College of Technology,
Coimbatore, India
Email:
Rajeevirajkarthikeyan@gmail.com

Abstract:

In this article, the effect of cross-sectional geometry on the flow behaviour of hydrogen in a polymer electrolyte membrane fuel cell is studied using a steady state computational model. Three geometric shapes: semi-circular, triangular and rectangular are considered in this study. The results show that the triangular geometry has the highest velocity and pressure drop in the channel, while the lowest is by the rectangular geometry. The velocity profiles of all three geometries are found to be parabolic in the fully developed region, with the triangular geometry having the narrowest at 1/3rd of the base height and hence the maximum velocity starts at that line. The reformer kinetic energy values are found to be highest at the inlet and reduce at fully developed regions. From this analysis, a rectangular section (or) a semi-circular section is having uniform flow distribution and low turbulence and is suitable for the fuel cell flow applications.

Keywords: Fluid flow, Turbulence, kinetic energy, Pressure drop, Velocity distribution, Geometric Effect.

1. INTRODUCTION

Proton exchange membrane fuel cells are a promising technology for clean and efficient power generation. Essentially, they convert the chemical energy of the reactant gases into electrical energy, without combustion. These fuel cells are useful in a variety of applications like stationary power generation, mobile transportation, and portable energy generation devices.

One of the key challenges in the development of proton exchange membrane fuel cells is the design of flow channels. The flow channels must be designed to accommodate a high flow rate of gases in the channels while minimizing the pressure drop and turbulence [1]. The cross-sectional geometry of the flow channel is an important factor that affects the behaviour of the gases. In this article, we investigate the effect of cross-sectional geometry on the flow behaviour of the hydrogen across three different geometries: semi-circular, triangular and rectangular. In this study, we compare the velocity, pressure and reformer kinetic energy profiles for these three geometries. The effect of cross-sectional geometry on the flow behaviour of the fluids has been extensively studied in the literature. Certain studies investigated the effect of channel geometry on the pressure drop in PEMFCs and established that the pressure drop was inversely proportional to hydraulic diameter [2]. Those studies concluded that, the pressure drop was higher for the sharp corners as well. Another study investigated the effect of geometry on the mass transport for PEMFCs. They found that the mass transport for the channel with larger aspect ratio was higher [3]. The mass transport was lower at the sharp corners as well. Other studies investigated the effect of geometry on the flow distribution and heat transfer in PEMFCs [4]. They found that the flow distribution was more uniform and heat transfer was effective for channels with larger aspect ratio. On the other hand, the flow uniformity and heat transfer were reduced at the sharp corners as well.

II. METHODOLOGY

A. Numerical Details

The CFD simulations were performed using ANSYS Fluent 2023 (Station Version). The computational domain was a 3D axis long channel, with different cross-sectional areas, respectively accommodating in the particular geometry. In this study, three geometrical sections (semi-circular, triangular and rectangular) are

considered and the dimensions are tabulated below (Table 1). Meshing is performed using patch conformation with tetrahedrons. The size of element size is parametrized for the grid independence study. The value of averaging velocity is used to perform the mesh number test. The mesh element size is maintained the same for other sections as well. The results of grid independence are tabulated below (Table 2). From this, 1e-4 m is selected as the mesh element size for the study.

Table 1. Dimensions of the Geometry

Serial Number	Name of the Geometry	Length of the channel (mm)	Width of the channel (mm)	Depth of the channel (mm)
1	Semi-circular	100	2	1
2	Triangular	100	2	1
3	Rectangular	100	2	1

Table 2. Grid Independence Test

Serial Number	Geometry	Minimum mesh element size (m)	Number of elements	Velocity (m/s)
1	Semi-circular	1.00e-4	6,56,487	1.0028
2		1.00e-4	6,56,482	1.0028
3		1.00e-4	6,68,511	1.0028
4		0.00e-4	9,37,489	1.0028

During the solution procedure, the following conservative relations are taken into consideration:

A) Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \tag{1}$$

B) Navier-Stokes equation:

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u u) = -\nabla p + \nabla \cdot \tau + \rho g \tag{2}$$

Table 3. Properties of hydrogen used for flow simulation

Density (kg/m ³)	0.0899
------------------------------	--------

SGS + k- ω model is used to capture the turbulence effect for this low Reynolds flow study [15] at sub-grid flow structure. The first order study is k- ω model. The properties are obtained in the table below (Table 3). The simulation is run using an iterative solver for studying the steady state characteristics of the system. The pressure and velocity plots were analyzed to determine the flow behaviour of hydrogen in the three geometries.

Viscosity (kg/m.s)	8.411 mPa
--------------------	-----------

B. Model Validation

In order to ensure that the model accurately models the physical system of interest, we validate with velocity obtained from analytical calculations:

$$Q = \Delta p$$
 (3)

$$\frac{\Delta p}{L} = \pi r^2 (2 \cdot \mu)$$
 (4)

III. RESULTS AND DISCUSSION

A. Effect of geometry on velocity:

The velocity profiles for all the three geometries are shown in Figure 1. The triangular geometry has the

$$\mu = 1.27816 \text{ cP}$$

The average velocity as is estimated by the simulation for a circular mesh is 1.3 m/s. This difference is due the weighted average of velocity taken at the outlet, taking into effect the boundary layer development. Since the problem is quite simple, this model validation is applicable for further studies undertaken in this article.

highest maximum velocity, followed by the semi-circular geometry and the rectangular geometry. The maximum velocity of the triangular geometry is 4.4 m/s, compared to 2.8 m/s for the semi-circular geometry and 2.0 m/s for the rectangular geometry.

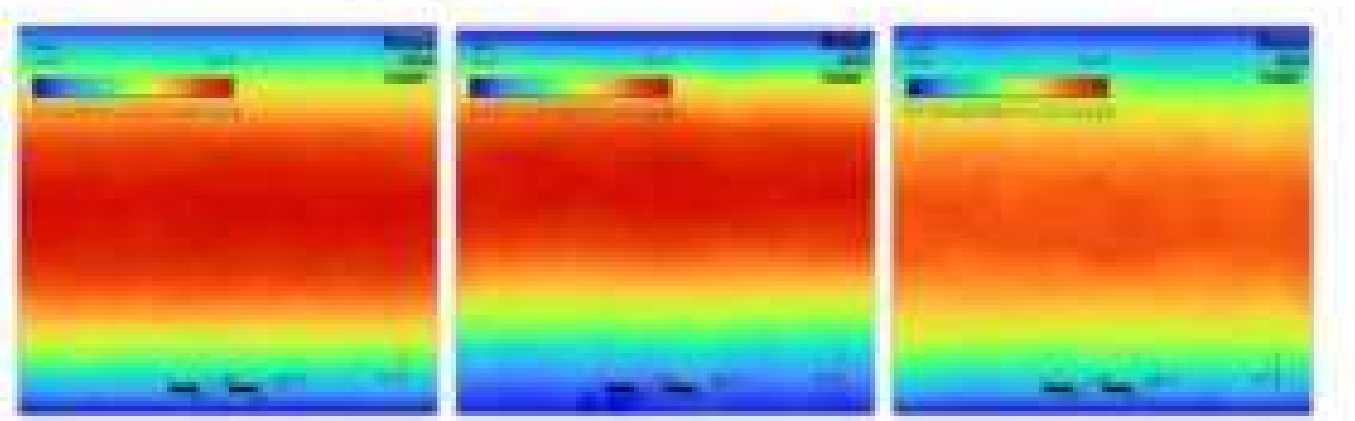


Figure 1. Distribution of velocity as a function of geometry in flow channels at fully developed regions, (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometry

The velocity profile along the x -length for fully developed flow is a characteristic feature of fluid flow in channels and pipes. In fully developed flow, the velocity profile remains constant along the x -length, indicating that the flow is no longer influenced by the entrance conditions. The velocity profile for fully developed flow is typically parabolic in shape, with the maximum velocity occurring at the center of the channel or pipe and decreasing towards the walls. On the entry, due to sudden involvement in boundary layer

as fluid starts to enter the channel, velocity profiles (Figure 2) are parabolic with respect to the geometry of the geometry as shown in the figure below. The velocities for semi-circular, triangular and rectangular regions are 1.3 m/s, 2.05 m/s and 1.01 m/s respectively. The figure below (Figure 3) illustrates the parabolic velocity profile for the channel at fully developed region. The velocities for semi-circular, triangular and rectangular regions are 2.5 m/s, 4.2 m/s and 1.8 m/s respectively.

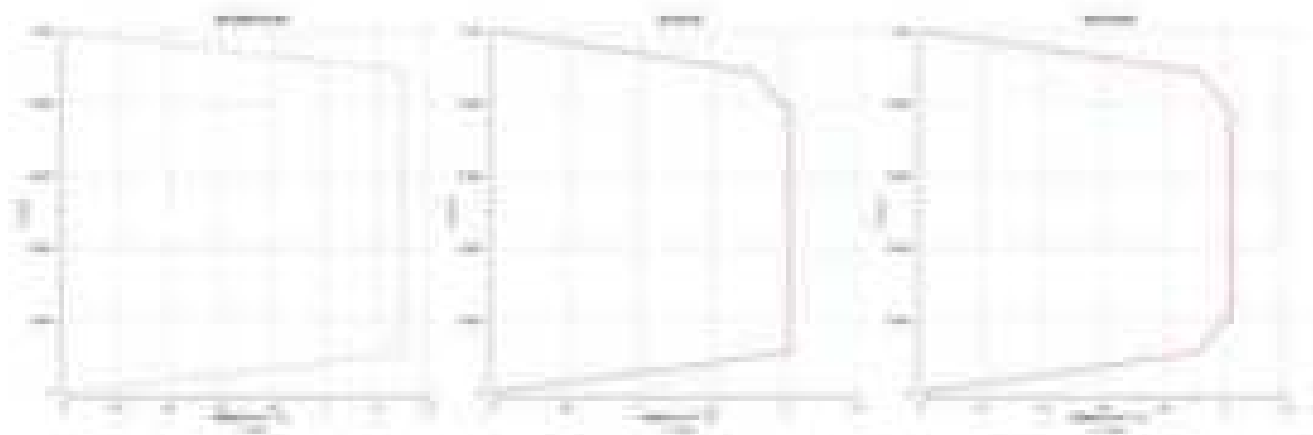


Figure 2. Distribution of velocity at the entry region in flow channels (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometry

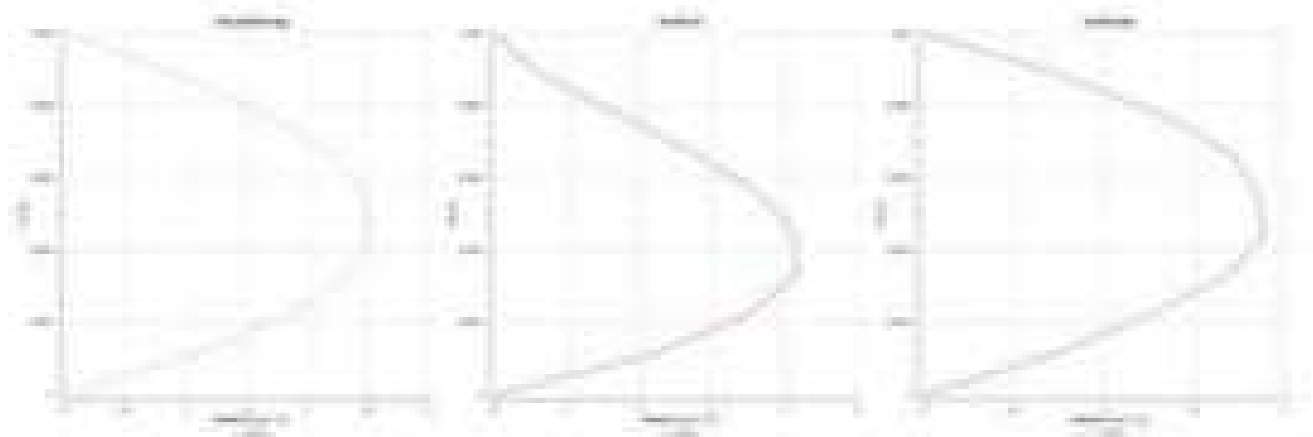


Figure 3. Distribution of velocity at the fully developed region in flow channels (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometry

The development of the velocity profile from the entrance to the fully developed region is a result of the interaction between inertia and viscous forces. As the fluid enters the channel or pipe, it experiences a sudden change in velocity, which creates a boundary layer near

the walls. The boundary layer is a thin layer of fluid where viscous forces are dominant and the velocity is reduced. As the fluid travels downstream, the boundary layer grows thicker and the velocity profile gradually develops until it reaches a fully developed state.

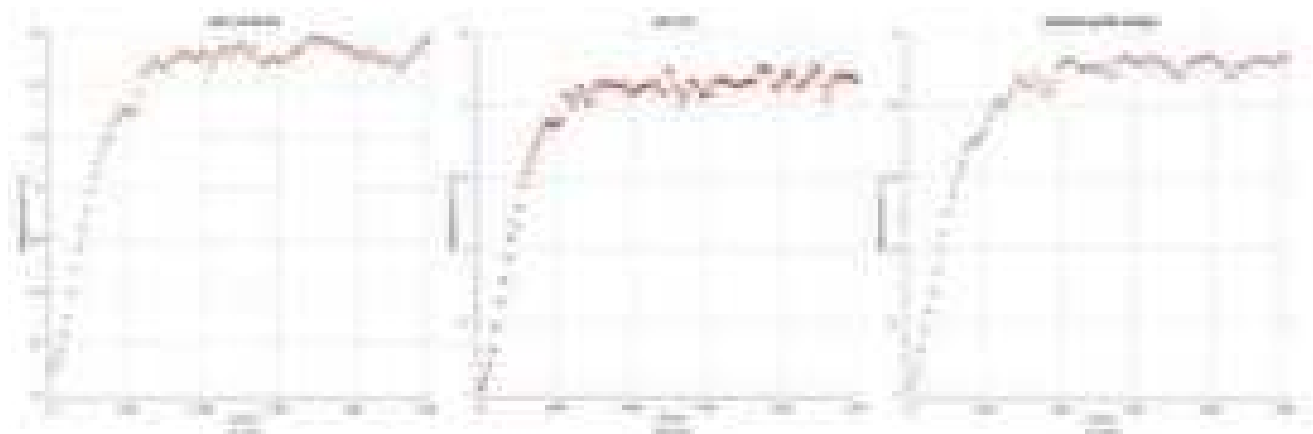


Figure 4. Distribution of velocity along x-direction – Entrance to fully developed region. (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometry

The length of the entrance region required for the flow to become fully developed depends on the Reynolds number of the flow. The Reynolds number is a dimensionless parameter that characterizes the ratio of inertial forces to viscous forces in a flow. For low Reynolds number flows, the entrance region is relatively short, while for high Reynolds number flows, the entrance region can be quite long. In this case, all three geometries show a similar entrance length of 2 mm, illustrated from the above figure (figure 4).

B. Effect of geometry on pressure:

Pressure plots are used to visualize the pressure distribution in the fluid flow. Pressure in a flow domain varies with respect to location and the instantaneous velocity. Navier Stokes equations are simultaneously solved for iteration until 1% of residual, for pressure

plot generation. The pressure drop in fluid flow relates to the energy loss in fluid due to friction against the walls of the channels. The triangular geometry has the highest pressure drop because it has the largest surface area of contact with the fluid. In addition to the surface area, the shape of the geometry also affects the pressure drop; the sharp edges of a triangular flow geometry create a high flow separation, thus leading to high pressure drop.

The pressure plots for the three geometries are shown in the figure below (figure 5). The triangular geometry has the highest pressure drop, followed by the semi-circular geometry and the rectangular geometry. The pressure drop for the triangular geometry is 67.1 Pa, compared to 23.7 Pa for the semi-circular geometry and 13.4 Pa for the rectangular geometry.



Figure 5. Distribution of pressure drop along the length of the channel (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometries

C. Effect of geometry on turbulent kinetic energy:

Turbulent kinetic energy measures the average kinetic energy of the eddies in a turbulent flow. This is a very important factor that affects the flow behavior, heat transfer and mass transfer in fluid flow. At inlet, the TKE values are at the highest due to sudden change in velocity; this disturbance creates boundary layer near

the walls of the channels. Here, the velocity is reduced, and turbulence is high, as shown in the figure below (figure 6). At the entrance the TKE values for semi-circular, triangular, rectangular geometry for the given boundary given $0.0008 \frac{m^2}{s^2}$, $0.0016 \frac{m^2}{s^2}$ and $0.004 \frac{m^2}{s^2}$ respectively.

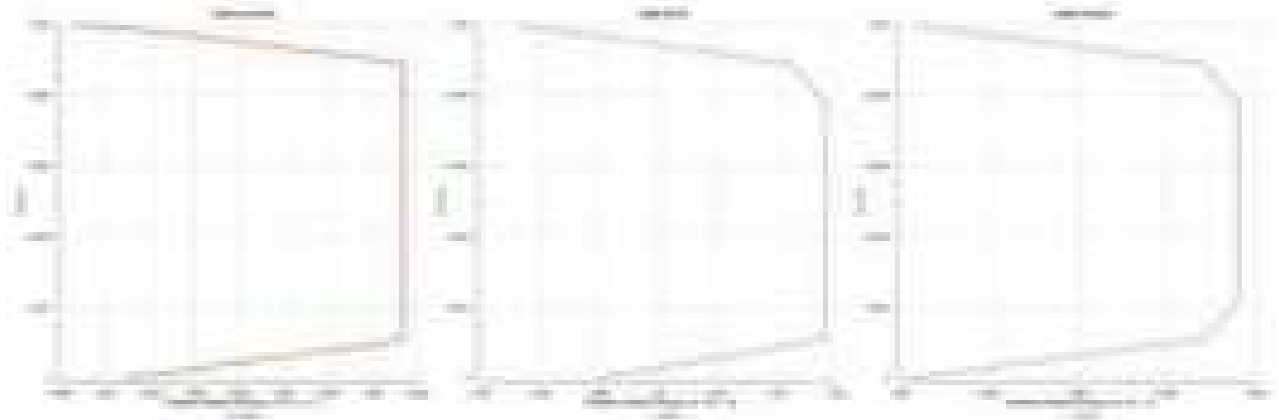


Figure 6. Distribution of turbulent kinetic energy at the inlet of the channel (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometry

As we move away from the entrance to the fully developed region, the boundary layer thickens, and turbulence intensity reduces. In the fully developed region (Figure 7), the flow is no longer influenced by the entrance condition at the parabolic velocity profile. However, the TKE values are still non-zero due to the

interaction of flow with walls. In the fully developed region, the TKE values for semi-circular, triangular, rectangular geometry for the given boundary given 2ϵ is $\frac{1}{2}U^2$, 1.5ϵ and 2.4ϵ respectively.

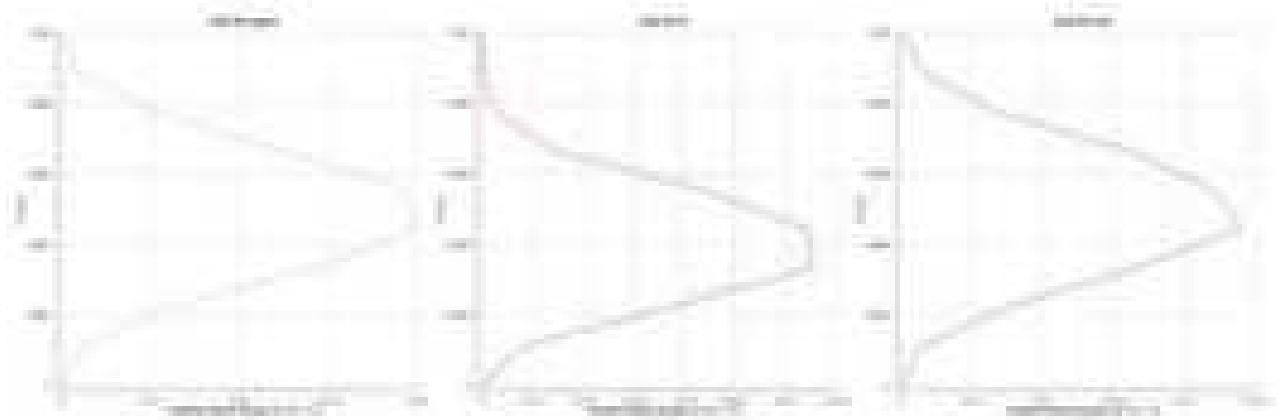


Figure 7. Distribution of turbulent kinetic energy at the fully developed region of the channel (a) Semi-circular geometry (b) Triangular geometry and (c) Rectangular geometry

The triangular geometry has the highest TKE values in both the inlet and the fully developed region because it has the sharpest corners. The sharp corners create areas of high flow separation, which can increase the turbulence intensity and TKE values. The semi-circular and rectangular geometries, on the other hand, have smoother walls and less flow separation, which contributes to their lower TKE values.

IV. CONCLUSIONS

The study's findings demonstrate that the cross-sectional geometry of the flow channel has a

substantial impact on the flow behavior of hydrogen in a PS/MFC. This implies that the shape of the channels can significantly influence how hydrogen flows through the channels, thus affecting the performance of the fuel cell.

Triangular Geometry: Highest Velocity and Pressure Drop

The triangular geometry exhibited the highest maximum velocity and pressure drop among the three geometries examined. This suggests that hydrogen flows more rapidly and encounters greater resistance in

triangular channel compared to semi-circular or rectangular channels. This could be attributed to the triangular geometry's sharp corners, which can induce flow separation and recirculation, leading to increased pressure drop.

Parabolic Velocity Profiles

The velocity profiles for all three geometries were found to be parabolic in the fully developed region. This indicates that the velocity distribution across the channel becomes more uniform as the flow progresses downstream. The triangular geometry, however, exhibited a shift in the maximum velocity towards the corner, which is located at 1/3 of the base height. This deviation from the typical parabolic profile could be due to the triangular geometry's unique shape and the influence of its corners.

Highest TKE Values at Inlet and Lowest in Fully Developed Region

The TKE values were found to be highest at the inlet and lowest in the fully developed region for all three geometries. This trend indicates that turbulence is more

intense at the beginning of the flow path due to the sudden change in velocity as the fluid enters the channel. As the flow progresses downstream, the turbulence intensity decreases, leading to lower TKE values.

Implications for PEMFC Design

The findings of this study have important implications for the design of PEMFCs. The choice of cross-sectional geometry for the flow channels can significantly impact the flow behavior of hydrogen and, consequently, the overall performance of the fuel cell. Triangular channels, while exhibiting higher maximum velocity and pressure drop, could be advantageous in applications where rapid hydrogen transport is critical. However, for applications requiring lower pressure drops and reduced turbulence, semi-circular or rectangular channels might be more suitable.

Overall, this study provides valuable insights into the relationship between cross-sectional geometry and flow behavior in PEMFCs. By understanding these relationships, engineers can optimize flow channel design to improve PEMFC performance and efficiency.

LIST OF ABBREVIATIONS

Abbreviation/Symbol	Explanation/Units
PEMFC	Proton Exchange Membrane Fuel Cell
TKE	Turbulent Kinetic Energy $\frac{m^2}{s^2}$
ρ	Density $\frac{kg}{m^3}$
u	Velocity $\frac{m}{s}$
∇	Divergence
R	Acceleration due to gravity $\frac{m}{s^2}$
$\bar{P}$	Pressure $\frac{N}{m^2}$
t	Time s
τ	Shear Stress $\frac{N}{m^2}$
Θ	Loss coefficient

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Science and Engineering Research Board (SERB) for funding this research under Grant No. MTR/2020/011. This support is gratefully appreciated.

REFERENCES

[1] Arora, S., K. C. Paroo de Lenc, and V. C. Walsh. "Channel design—the variable plate parallel electrode geometry: an editorial review." *Journal of The Electrochemical Society* 167.2 (2020): 021504.

[2] Wilkerson, Tami, et al. "A comprehensive study of the effect of bipolar plate (BP) geometry design on

the performance of proton exchange membrane (PEM) fuel cells." *Renewable and sustainable energy reviews* 111 (2019): 774-791.

[1] Shen, Jun, Donglai Yu, and Xian-Hua Chen. "Enhancement of mass transfer in a proton exchange membrane fuel cell with bionicity in the flow channel." *Applied Thermal Engineering* 149 (2018): 1406-1418.

[2] Yu, Yuan, et al. "Effects of distribution area design on flow uniformity and pressure drop in PEMFC." *Journal of the Electrochemical Society* 158.9(2021): 094502.

[3] Amaguchi, Masafumi, Urban Schwaberg, and Richard H. Harrison. "Evaluation of turbulence correction methods for slip velocity prediction in SNT by a turbulent model framework." *International Journal of Heat and Fluid Flow* 75 (2019): 125-132.

Effect of Manifold and Distributor Dimensions on Flow Characteristics in PEM Fuel Cell Stack

Dharm Kumar P

Research Scholar,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore
Email: dharmkumar.psg@gmail.com

Karthikeyan P

Professor,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore
Email: prk.seshu@psgtech.ac.in

Vijai Karthi V

Research Scholar,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore
Email: vijai.karthi.v.77@gmail.com

Heekathu R

Research Scholar,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore
Email: hheekathu@psgtech.ac.in

Abstract

The dimensions of the manifold and distributor in a Proton Exchange Membrane (PEM) fuel cell stack play a crucial role in determining the flow characteristics, which can significantly impact the performance and efficiency of the fuel cell stack. In the present study, the velocity distribution, pressure drop in both manifold and distributor is numerically studied on anode side of a 5 cell stack with serpentine channel design. Four study cases with different manifold diameter and distributor width varied as 4 mm x 2 mm (case 1), 4 mm x 3 mm (case 2), 6 mm x 2 mm (case 3) and 6 mm x 3 mm (case 4) is considered for the evaluation. Among the designs, the case 3 manifold and distributor combo delivered better velocity and pressure drop across the flow field. The input velocity at the distributor entrance and flow channel entrance made the flow uniform throughout the channels in the active area.

Keywords: PEMFC, reactant flow, manifold distributor, velocity distribution

INTRODUCTION

A Proton Exchange Membrane Fuel Cell (PEMFC) stack is a clean energy technology which could potentially replace the fossil fuel resources for power generation. As a type of fuel cell, it operates on the principle of electrochemical reactions to convert chemical energy directly into electrical power. PEMFC is known for its

high power density, quick start-up times, and versatility for various applications, including transportation, stationary power generation, and portable devices [1]. In order to operate the fuel cell stack efficiently, the uniform reactant supply and product removal from the stack is highly important. The reactant supply to each cell of the stack governs better stack efficiency. The manifolds at inlet and outlet of the stack plays a crucial role on supply of reactants to both anode and cathode side of individual cells and simultaneously removes the reaction products and product water from stack [2]. The manifolds are designed in such a way that the pressure drop in manifold should be an order of magnitude lower than the pressure drop observed in flow channels. Along with pressure drop, flow velocity is also an important parameter to be considered to avoid internal leakage and to eliminate the reactants gets trapped inside the stack [3]. The manifold can either be internal or external and the flow pattern followed in the stack are U and Z type in general [4]. The hole for manifold is often designed as circular, rectangular and square in shapes [5]. Apart from manifold design, the design of distributor which connects the manifold and each flow channel of the stack also received higher attention from research community for effective transport of reactants [6]. The shape and dimensions are two vital factors upon design the manifold and distributor. Many research studies reported with different manifold shape and distributor in order to ensure the better reactant distribution. Labadie et al [7], observed jet flow behaviour when the circular geometry changes to rectangular when entering to manifold which causes the flow

maldistribution. The mass flow distribution in the final 20% of the channels show initial channels due to high velocity [8], reducing channel hydraulic diameter and increasing the manifold dimension [9], reducing channel width and increasing pressure drop [10], providing double inlet and outlet manifold configurations [11] are some of the findings for flow distribution in manifold as well as in flow channel. This work emphasizes the effect of manifold and distributor dimensions on inside side of a 5-cell stack with supercritical flow field. The flow velocity in manifold and distributor and pressure drop in flow channel are numerically evaluated and the best combination is identified.

II. METHODOLOGY

A. Geometry model

The inside component of a 5-cell stack is considered for the analysis. Four different combinations of manifold diameter and distributor width viz., 4 mm x 2 mm (case 1), 4 mm x 3 mm (case 2), 6 mm x 2 mm (case 3) and 6 mm x 1 mm (case 4) are analysed. In all cases, the width and depth of flow channel is taken as 2 mm and 1.25 mm respectively. Fig.1, shows the 5-cell inside channel and flow channel with ellipsoid cases 1 to 4. The active area is assumed as 66 cm². The channel dimension and fluid properties are given in table 1.

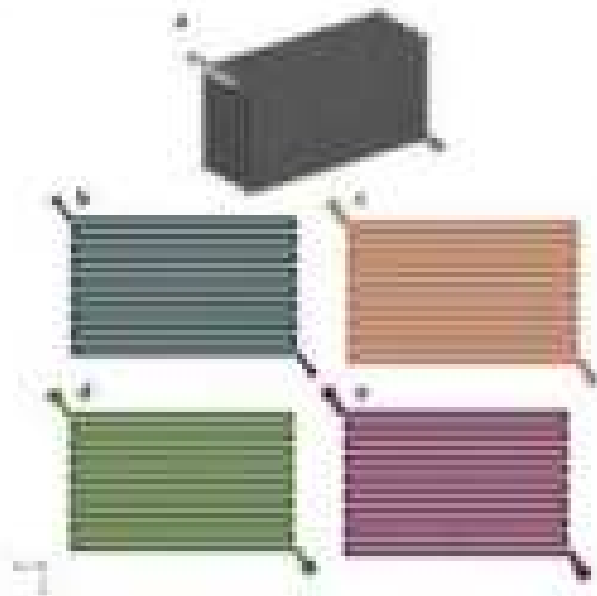


Fig.1(a) 5-cell stack, (b) case 1, (c) case 2, (d) case 3 and (e) case 4

B. Mathematical model

A three dimensional model is solved for continuity and momentum equations to analyse the flow characteristics. A few assumptions like steady flow, ideal gas behaviour of

reactants and laminar flow are considered. The governing equations used are provided as follows.

Continuity equation,

$$\nabla \cdot (\rho u) = 0 \tag{1}$$

Where ρ and u are density and velocity for mass conservation.

Momentum equation,

$$\rho(u \cdot \nabla)u = \nabla \cdot (-P + \tau) \tag{2}$$

$$\tau = \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\rho(\nabla \cdot u)I \tag{3}$$

Where P , τ and μ are the pressure, stress tensor and dynamic viscosity respectively.

Table. 1 Geometric parameter and fluid properties

Parameter	Value
Channel width (m)	0.002
Channel depth (m)	0.002
Cell length (m)	0.1
Cell width (m)	0.006
Flow rate (mol/s)	2×10^{-5}
Hydrogen density (kg/m ³)	0.082
Dynamic viscosity (Pa.s)	8.76×10^{-6}

III. RESULTS AND DISCUSSION

The velocity distribution and pressure drop in manifold and distributor is evaluated for detailed discussion.

A. Velocity distribution

Fig.2a to 2d, shows the velocity distribution from distributor at inlet manifold to cell 1, cell 3 and cell 5 for all four cases. The maximum velocity is reported in case 1 and minimum is reported in case 4 and whereas, the case 3 is reported moderate velocity. In all cases the intensity of velocity at inlet manifold is reduced when moving from cell 1 to cell 5 due to flow is side-attached through each cells. Due to smaller manifold diameter and maximum distributor width the velocity in case 1 is high. In case 1 and case 3 the velocity in distributor and channel is almost similar in all the cells. However, this behaviour is not observed in case 2 and case 4 where velocity has notable variation in distributor and at inlet of channels.

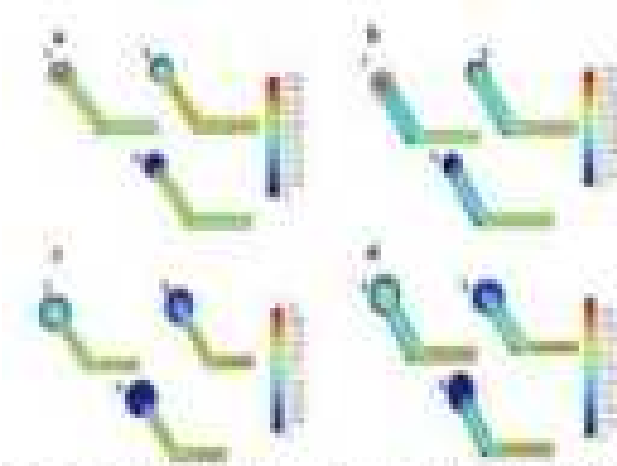


Fig.2. velocity (m/s) distribution at inlet distributor and channels of cell 1, 3 and 5 from (a) case 1 to (d) case 4

Though velocity is low in distributor, a sudden increase at channel entrance creates outlet effect along the channel path which may leads to reactant leakage inside the stack. Though velocity is high in case 2 compared to case 4, the minimum variation in velocity at distributor and flow channels of all the cells nullifies the outlet impact and causing the uniform flow. As, case 1 is having high velocity than also inlet and, Hence, case 2 is considered as suitable case for better flow distribution.

As like velocity distribution in distributor, fig. 3(a) to 3(d) and fig. 4(a) to 4(d) shows the velocity variation in inlet and outlet manifolds respectively.

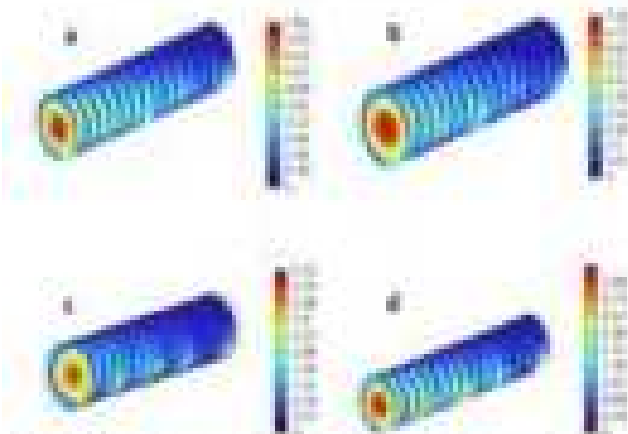


Fig.3-velocity (m/s) distribution at inlet manifold from case 1 to case 4

At inlet manifold, the velocity of reactant decreases along the manifold length due to reactant passes through each cell. Whereas, the reactant inlet is observed where the excess reactant converges from cell 1 to last cell. The velocity at inlet manifold is similar to velocity in distributor but the outlet manifold shows reduced velocity

in all cases. Due to pressure drop in the flow channel the velocity in outlet manifold is low.

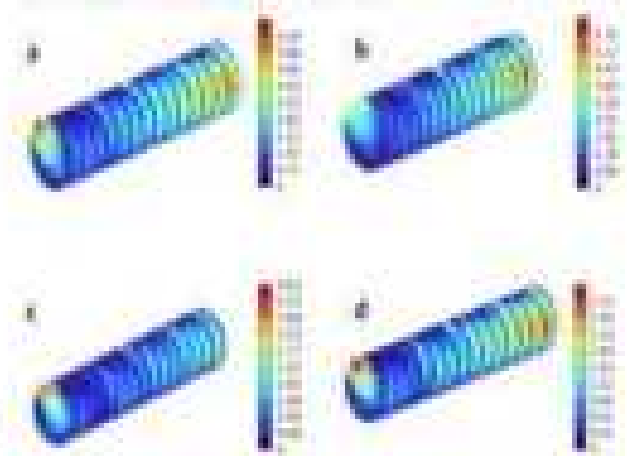


Fig.4 velocity distribution (m/s) at outlet manifold from (a) case 1 to (d) case 4

B. Pressure drop

The pressure in 4 case manifold is higher than the pressure in 6 case manifold. Fig. 5(a) to 5(d) shows the pressure drop at the first cell from case 1 to case 4.

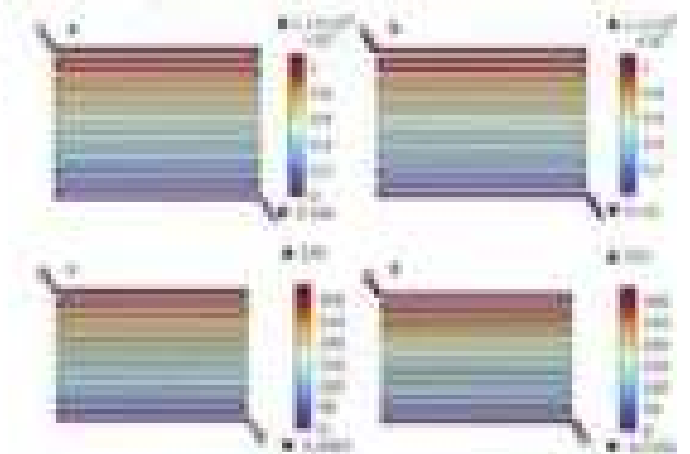


Fig. 5. Pressure drop (Pa) from (a) case 1 to (d) case 4

Hence, the stack is analyzed for flow distribution and re-electrochemistry is involved the pressure drop is almost similar in all cells of the stack. The pressure drop indicates that the manifold dimension has greater impact than distributor dimension. Larger the manifold smaller is the pressure drop and vice-versa. In case 1 and case 2 the manifold size is 4 mm but the distributor width is 2 mm and 1 mm. However, the pressure drop is almost same in both cases. Similarly, in case 3 and case 4 the manifold is diameter is 6 mm and the distributor width 2 mm and 3 mm respectively. In these two cases also the pressure drop

is similar. Hence, the selection of manifold diameter is more important upon designing the fuel cell stack.

IV. CONCLUSIONS

In the present study the effect of manifold and distributor diameter on flow distribution was analyzed. Two cases were considered for velocity and pressure drop evaluation. The important findings of the study is provided as follows:

- Smaller manifold diameter and distributor diameter with case 1 and case 2 leads to high flow channel velocity, which may cause coolant leakage inside the stack.
- Manifold with larger manifold diameter and smaller distributor width (case 2) has equal velocity at both distributor and channel which would result in more uniform distribution of reactant in the stack.
- Larger manifold and distributor (case 2) had low velocity in the distributor. However, at channel entrance the velocity drastically increases and this leads to flow impact in the channel and subsequently causes leakage.
- Pressure drop in larger manifold is less and in smaller manifold is more. The distributor diameter had no impact on pressure drop.

REFERENCES

- [1] Ponnanjey D, Palanisamy R, Chandran M, Viswanathan VK. Investigating the impact of variable speed rate cathodic flow field on temperature distribution and performance in a PEM fuel cell. *Numer Heat Transf Part A Appl* 2023;61: 23. <https://doi.org/10.1080/10407773.2023.2273274>.
- [2] Mustafa M, Ranaivosoa HS, Faraj J, Faraj A, El Hage H, Khalid ME. Impacts of anode flow uniformity on fuel cell performance and cooling up: Comprehensive review, critical analysis and potential recommendations. *Int J Hydrogen Energy* 2021;46:12342-51. <https://doi.org/10.1016/j.ijhydene.2020.06.071>.
- [3] Fromm-Bachle. Stack design. In: F. Bachle (Eds). *PEM Fuel Cells: Theory and Practice*. Elsevier Academic Press; 2005:187-204.
- [4] McKie J, Meyers F, Fairbrother L, Wainman J, Hirschel A, Cieske F, et al. Investigation and equalization of the flow distribution in a fuel cell stack. *J Power Sources* 2020;449:227546. <https://doi.org/10.1016/j.jpowsour.2019.227546>.
- [5] Huang F, Qin D, Liu X, Yi P, Peng L. Performance evaluation of commercialized proton exchange membrane fuel cell stacks considering air flow distribution in the manifold. *Energy Convers Manage* 2020;200:112236. <https://doi.org/10.1016/j.enconman.2019.112236>.
- [6] Liu RH, Majum EEL, David WRW, Bock ML, Hosaini T. Three-dimensional study of stack on the performance of the proton exchange membrane fuel cell. *Energy* 2010;35:334-43. <https://doi.org/10.1016/j.energy.2009.12.021>.
- [7] Lohk J, Dong M, Gu JK. Flow and pressure distribution in fuel cell manifolds. *J Fuel Cell Sci Technol* 2010;7:1-8. <https://doi.org/10.1115/1.4001316>.
- [8] Rahman-Pour M, Sanghani AR, Aghajani F. Manifold Design in a PEM Fuel Cell Stack to Improve Flow Distribution Uniformity. *Sustain* 2022;14. <https://doi.org/10.3390/su142313702>.
- [9] Park J, Li X. Effect of flow and temperature distribution on the performance of a PEM fuel cell stack. *J Power Sources* 2006;162:444-50. <https://doi.org/10.1016/j.jpowsour.2005.07.030>.
- [10] Qiu Y, Liu G, Cheng Y, Du Q. Modeling and design of PEM fuel cell stack based on a flow optimal method. *Appl Therm Eng* 2018;144:411-23. <https://doi.org/10.1016/j.applthermaleng.2018.06.078>.
- [11] Liu RH, Majum EEL, David WRW, Bock ML, Hosaini T. Structural analysis of flow distribution behavior in a proton exchange membrane fuel cell. *Cellulose* 2013;46:4884-93. <https://doi.org/10.1016/j.cellulose.2013.08.003>.

Standardization of fermentation conditions for the production of bio-ethanol from matured coconut water

R.S. Vidhya Ganesh¹

Dept. of Agricultural Microbiology
Tamil Nadu Agricultural University
Email: vidhyaganesh1989@gmail.com

R. Parimala devi²

Dept. of Renewable Energy Engineering
Tamil Nadu Agricultural University
Email: rparimala@tnau.ac.in

S. Karthikeyan³

Dept. of Agricultural Microbiology
Tamil Nadu Agricultural University
Email: skarthi@tnau.ac.in

R. Manohar⁴

Dept. of Renewable Energy Engineering
Tamil Nadu Agricultural University
Email: rmanohar@tnau.ac.in

V. Jayashankar⁵

Dept. of Renewable Energy Engineering
Tamil Nadu Agricultural University
Email: vijayashankar@tnau.ac.in

B. Murugesan⁶

Dept. of Agricultural Business
Management
Tamil Nadu Agricultural University
Email: murugesanb@tnau.ac.in

Abstract

Pollution of natural, environmental and water resources caused through industrial wastes is becoming a major concern nowadays. Agro-industries contribute 14-15% for the cause of pollution. As the wastes generated from agro-industries are of biological origin, they can be effectively reused, if their alternate uses are explored. Coconut industry is one of the major agro-industry where wastes are generated in large quantity. Wastes generated in coconut industry include coconut shell, coconut husk, coconut water and oil cake. The modified coconut industry waste includes coconut water which is generated during copra processing. Coconut water which contains most nutrients of sugar, lipids, organic acids, etc and hence they can be used as a feedstock for bioethanol production. In this study an attempt was made to standardize fermentation conditions for enhanced bio-ethanol production from matured coconut water. Standardized fermentation conditions for enhanced bio-ethanol production were temperature-37.5°C, pH-5.5 and incubation period-96 hours with *Saccharomyces cerevisiae*. From our study it was inferred that matured coconut water is a potential source for production of bio-ethanol and this will lead to circular economy in coconut processing industry.

Keywords: Matured coconut water, Bio-ethanol fermentation

1. INTRODUCTION

Coconut is one of the primary plantation crops grown in India, covering approximately 1875 hectares water cultivation. Tropical Asian nations lead in global coconut output, with Indonesia, Philippines and India accounting for more than 75% of total production. India ranks third with an impressive net harvest of 23,662

million nuts from 61 thousand hectares, according to latest records. Additionally, coconut is renowned for its wide array of by-products including coconut milk, virgin coconut oil, coconut chips and meal/flakes. Indeed, this matured coconut water due to its rich nutritional properties could be used as a potential feedstock for bioethanol generation. Industrial mechanization is a boon to the developing nations with the advantages such as reduction in labour costs and increased productivity. Increased number of industries and mechanization has resulted in increased waste disposed into the environment. Agro-industries contribute to waste disposed to a considerable level and this waste management costs huge to the respective industries. Conversion of these biodegradable waste into biofuels and value-added chemicals is gaining momentum as it holds two major advantages such as additional revenue and effective waste management. Copra industry is one of the major coconut based agro-industry, in which a large volume of coconut water is generated and discarded into the environment. This leads to changes in soil properties, groundwater fouling problems and erosion of land used due to fertilization. Coconut water is nutritionally rich and hence this can be used as a raw material for production of biogas and bio-ethanol. While water hyacinth is the most preferred raw material, the supply however had been recorded to increase more exhausted due to the rise of fermentation industries. Furthermore, this had also affected the increase in the marketing price in recent years. Therefore, in the effort to employ household recreation, overly matured coconut water (MOW), which often regarded as waste, seems to be an attractive renewable carbon source for ethanol fermentation industry. Hence it is proposed that utilization of MOW for ethanol production will be advantageous as the

MCW may support immediate yeast growth and ethanol production.

II. MATERIALS AND METHODS

A. Physicochemical analysis of MCW:

Sample of Matured coconut water was collected from 10 coira industries located in Thrippunithura. Matured coconut water was filtered through muslin cloth used for analysis.

Total acidity:

Total acidity was determined by titrimetric method. Standard procedure given by International Science Congress Association was followed. Ten different samples of matured coconut water were taken in a conical flask with phenolphthalein as indicator. The solution was titrated against 0.1N NaOH solution. The progress of colour change was observed and calculated with

$$\text{Total acidity} = \frac{\text{nitrate value} \times 1000}{\text{volume of the sample taken}}$$

The total acidity is expressed in terms of CaCO_3 (mg).

Total lipids:

Total lipids estimation was done by KJH method. Ten samples of matured coconut water were taken with phenolphthalein as indicator and titrated against 0.1N potassium hydroxide. Total lipids were expressed in terms of (mg).

Total lipids:

$$= \frac{\text{nitrate value} \times \text{normality of KOH} \times 49}{\text{weight of the sample}}$$

Dissolved oxygen:

Dissolved oxygen was measured by modified Winkler's method. Ten samples of matured coconut water were taken in BOD bottles with 2ml of magnesium sulphate, alkali azide, and add 2ml of concentrated sulphuric acid. The mixture was titrated against sodium chromophate with starch as indicator. The dissolved oxygen was calculated with the formula:

$$\text{Dissolved oxygen} = \frac{V \times N \times 8 \times 1000}{\text{Weight of sample}}$$

Dissolved oxygen was expressed in terms of (mg)

Total suspended solid (TSS):

Total suspended solids were analysed with gravimetric method. Ten different samples of matured coconut water were taken and filtered through the Whatman No.1 filter paper. The filter paper was oven dried at 65°C for 2hrs. As the drying progressed the filter paper was weighed to have the final weight. The suspended solids were expressed in (mg) and calculated by

$$\text{TSS} = \frac{W_2}{W_1} \times \frac{1000}{V}$$

Where W_1 = initial weight, W_2 = final weight, V = volume of the sample

Total dissolved solids (TDS):

Total dissolved solids were determined by gravimetric method. Ten filtered samples of matured coconut water was taken in a porcelain dish and kept in the oven overnight at 105°C . As the drying progressed the weight was determined and calculated by

$$\text{Formula} = \frac{W_2}{W_1} \times \frac{1000}{V}$$

Where W_1 = initial weight of the porcelain dish, W_2 = final weight of the porcelain dish, V = volume of the sample (l) was expressed in (mg).

Total solids (TS):

Total solids were determined by the addition of total suspended solids and total dissolved solids

$$\text{TS} = \text{TSS} + \text{TDS}$$

Total sugar:

The total sugar content of MCW was calculated using DNSA method. It is calculated by multiplying the reducing sugar percentage by 0.05. The total sugar content was expressed in percentage (%).

$$\text{Total sugar} = \text{Reducing sugar percent} \times 0.05$$

Reducing sugar:

Reducing sugar was fermentable sugar. Ten samples of matured coconut water were taken in test tube containing 1ml of DNS reagent and kept in water bath for 20mins. As the progress in colour change occurs the supernatant was analysed in spectrophotometer at 540nm. The concentration was obtained by plotting the colour concentration against standard concentration.

Total protein:

Total protein was measured by biuret method. Biuret reagent was prepared by dissolving 1.5g of copper sulphate in 175ml of 2M sodium hydroxide, the volume was made up to 1litre. In a fresh clean test tube 0.5, 0.2ml of MCW was taken separately and 1ml of biuret reagent was added. Standard albumin solution was prepared and volume of 0.1, 0.4, 0.6, 0.8 and 1 ml was taken and added with one ml of biuret reagent. The solution was examined under UV spectrophotometer at 540nm. The concentration of protein was obtained by plotting the values in graph and expressed in (mg).

NPK content:

MCW samples were analysed for total NPK content by Kjeldahl method for nitrogen, spectrophotometric method for phosphorus, flame photometric method for potassium. For total nitrogen, 1 or 2ml of sample was taken in 200ml of Kjeldahl flask and 0.7g of mercuric oxide, 15 of potassium sulphate, and 10ml of concentrated sulphuric acid were added and kept for digestion overnight. The digested sample was taken in a conical flask and filtered

against 0.1N sodium hydroxide with methylam blue as indicator.

For total phosphorus, 1.0ml of sample was taken and 0.45ml of H₂SO₄ and 1.0ml of distilled water was added. About 0.04ml of ammonium molybdate and 0.4ml of ascorbic acid was added and the test tube was closed with screw cap. The mixture was heated to 100°C for 10min and allowed to cool. The samples were analysed by spectrophotometer at 820nm.

For total potassium, 1ml of MCW sample was taken in 100ml of distilled flask and added with 10 ml of triple acid mixture. The contents were digested till the colour disappears in sand bath. After digestion, the samples were made up of 100ml with distilled water. The samples were analysed by flame photometer.

B. Inoculum preparation

Saccharomyces cerevisiae available in the Department of Renewable Energy Engineering was used to conduct the fermentation studies. The yeast culture was streaked in Yeast extract Peptone Dextrose (YPD) agar (glucose 2%, peptone 2%, yeast extract 1%). After 24hrs of incubation single colonies were taken and inoculated in fresh YPD broth at room temperature. After incubation for a short period, the cells were centrifuged at 5000rpm for 10 min, then diluted in sterile distilled water and used for fermentation studies.

C. Fermentation conditions

Batch fermentation was carried out in 250 ml conical flask with 100 ml of fermentation medium. The Fermentation medium consists of Distilled Matured Coconut Water inoculated with 1% yeast inoculum and incubated at different temperature and pH. To determine the fermentation duration, reducing sugar levels were analysed every 24 hours by Do-Now's barbitol acid (DNS) method.

D. Optimization conditions

Experiments were designed using a Central Composite Design to study the different levels of two independent parameters. For two parameters, the model equation is

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2$$

Table 1. Central composite design levels

Variables	Units	Coded level of variables				
		-α	-1	0	+1	+α
X ₁ Temperature	°C	26.3	30	37.3	45	48.7
X ₂ pH	-	4	4.5	5.5	6.5	6.9

statistical Design Expert version 8.0.7 was used for design of experiments and graphical analysis of data. The design report generated a total of 13 sets of fermentation runs.

Ethanol quantification

The concentration of bio-ethanol were determined using HPLC (Shimadzu), with BGS-RAD column (HPLC-870), a refractive index (RI) detector. The mobile phase utilized was H₂O:CH₃OH with a concentration of 0.005M flowing at

a rate of 1.0 ml/min. A 20 µl injection volume was used for all samples. The concentration was determined by comparison with standards (1000µg/ml ethanol standard).

II. RESULTS AND DISCUSSION

Matured coconut water, a major industrial effluent from coir's industry (Thangaraj *et al.*, 2007), a nutrient-rich source is discarded into the environment as waste. This can be potentially used as a feedstock for production of bioethanol and this study was an attempt to standardize fermentation conditions for enhanced bio-ethanol production from matured coconut water and the results were presented below.

Ten samples collected from coir's industry were analysed for physicochemical properties. The results indicated the relatively high levels nutrient composition of MCW as follows: total potassium at 1972 mg/L, total solids at 664 mg/L, total acidity at 45 mg/L, total sugar at 1.43%, total nitrogen at 0.12%, total phosphorus at 10.8 mg/L, total lipids at 0.003mg/l and dissolved oxygen at 23 mg/l.

Table 2. Compositional analysis of Matured Coconut Water – TSS, TDS & TS

MCW Sample	TSS (mg/l)	TDS (mg/l)	TS (mg/l)
S1	1.0	613.0	614.0
S2	1.6	639.5	642.1
S3	1.1	596.4	598.5
S4	2.1	491.7	494.8
S5	2.9	613.8	614.7
S6	2.1	655.5	657.6
S7	4.9	496.2	495.1
S8	2.9	699.5	695.4
S9	1.5	732.7	744.2
S10	4.3	593.8	598.1
Average	2.4	601.4	604.9

*TSS-Total Suspended Solids; TDS-Total Dissolved Solids & TS-Total Solids

Table 3. Compositional analysis of matured coconut water – total acidity, total lipids & dissolved oxygen

MCW Sample	Acidity (mg/l as CaO)	Total Lipids (mg/l)	Dissolved Oxygen (mg/l)
S1	50	0.16	20.4
S2	18	0.08	20.0
S3	60	0.09	21.0
S4	50	0.07	22.8
S5	40	0.08	22.4
S6	40	0.07	19.6
S7	42	0.08	25.2
S8	40	0.07	20.0
S9	50	0.16	18.4
S10	38	0.09	20.0
Average	45.4	0.09	21.3

Table 4 compositional analysis of matured coconut water- total sugar, reducing sugar & total protein

M/C/W Sample	Total sugar %	Reducing Sugar (g/l)	Total protein (mg/l)
S1	1.93	7.5	0.091
S2	2.04	7.8	0.091
S3	1.96	7.6	0.092
S4	1.92	8.2	0.091
S5	1.94	7.3	0.097
S6	1.93	7.8	0.091
S7	2.00	7.5	0.091
S8	2.00	6.9	0.091
S9	1.95	7.3	0.091
S10	1.99	6.9	0.091
Average	1.97	7.5	0.092

Table 5. Compositional analysis of matured coconut water - NPK content

M/C/W Sample	Total Nitrogen (%)	Total Phosphorus (mg/l)	Total Potassium (mg/l)
S1	0.175	10.96	1523.0
S2	0.174	10.60	1033.0
S3	0.116	11.43	133.8
S4	0.102	10.46	853.0
S5	0.111	10.56	1154.0
S6	0.136	10.40	1067.0
S7	0.140	11.02	1267.0
S8	0.126	10.75	1156.0
S9	0.128	10.38	1044.0
S10	0.139	11.09	1097.0
Average	0.132	10.99	1072.8

Fermentation duration was determined by the decreasing concentration of reducing sugar. Initially, the reducing sugar concentration was about 7.5g/l after 3-days it was reduced to 7.4g/l and the final concentration was 2.3g/l at 90hrs. Spectrophotometric analysis for the determination of reducing sugar concentration is a very sensitive, low-cost, easy to handle, and accurate method. The present study demonstrated that the initial reducing sugar concentration gradually decreases during fermentation during bioethanol fermentation due to utilization of reducing sugar for bioethanol production.

Table 6. Reducing sugar concentration

Time	OD Value	Reducing Sugar (g/l)
0hrs	0.02785	7.5
30hrs	0.01983	7.4
45hrs	0.01478	7.0
72hrs	0.0123	3.20
90hrs	0.0099	2.3

In this optimization study, *Ascherbachium casei* was used to carry out fermentation trials. Fermentation trials were designed by design experts, with a total of 13 sets of two independent factors. The coefficient of Response Surface Model was evaluated by regression analysis and tested for their significance. The coefficient of determination (R^2) of the model is 0.9569. This makes the model more suitable for the relationship among the parameters. The summary regression values were tabulated in table 7 showed the actual and predicted ethanol yield.

Table 7 Summary of regression values

Values	Ethanol Fermentation
Std. Dev.	0.1112
Mean	1.50
C.V. %	4.69
R^2	0.9628
Adj. R^2	0.9191
Pred. R^2	0.7423
Adj. prediction	10.0204

The 13 sets of fermentation trials were generated (table 4) and its aim compares the difference between the actual and RSM-predicted yield (Fig. 1&2 represent the comparison between two yields). The optimal condition for bioethanol production from matured coconut wastewater was determined to be 37.5 $^{\circ}$ C and 5.3 pH. *Ascherbachium casei* rapidly utilized 50% of the fermentable sugar at this optimum temperature (Zappalari & Bond, 2011).

The optimization study results using RSM software suggests a -ve and a +ve value each a way of low pH and low temperature. However, the suggested pH of 4 and temperature of 25.5 $^{\circ}$ C yields the lower ethanol. Singh and Bhattach, (2012) studied the bioethanol production from alkali rice straw and reported that an increase in the pH decreases the ethanol yield and the same trend was observed in our study i.e., when the pH is increased from 4.5 to 5.3 the ethanol yield decreased. Findings of our study is in accordance with Peng and Chen, (2011) who reported that with increase in temperature beyond the optimum level the ethanol yield will be reduced. Lin et al., (2013) reported that high temperature reduced the ethanol production due to reasons such as inhibition of yeast cell growth, impairment in transportation of nutrients into the cell and toxic compound accumulation. The optimum temperature range for *Ascherbachium casei* growth and ethanol fermentation is reported to be between 20 $^{\circ}$ C to 30 $^{\circ}$ C, temperature above this threshold may hinder yeast cell proliferation and metabolic activity. Under

anaerobic conditions, *S. cerevisiae* converts glucose into ethanol and carbon dioxide without using oxygen. This fermentation pathway is less thermodynamically favourable than aerobic respiration, yet it allows the yeast to survive in low-oxygen environments. Research shows the optimal temperature for anaerobic respiration in *S. cerevisiae* to be approximately 30°C; temperatures above or below this point can influence fermentation performance and strain population dynamics.

Table 7. Optimization of fermentation trials

X ₁ : Temperature	X ₂ : pH	Ethanol yield(g/L)	
		Actual yield	RSM predicted
37.5	6.0	2.40	2.33
37.5	5.5	2.50	2.49
37.5	5.0	2.59	2.69
39.0	4.5	2.29	2.32
45	4.5	2.25	2.17
45	6.5	2.31	2.13
38	8.5	2.31	2.23
48.1	5.5	2.00	1.74
37.5	5.5	2.69	2.69
37.5	4.0	2.69	2.69
26.0	5.5	1.90	1.91
37.5	5.5	2.69	2.69
37.5	5.5	2.69	2.69

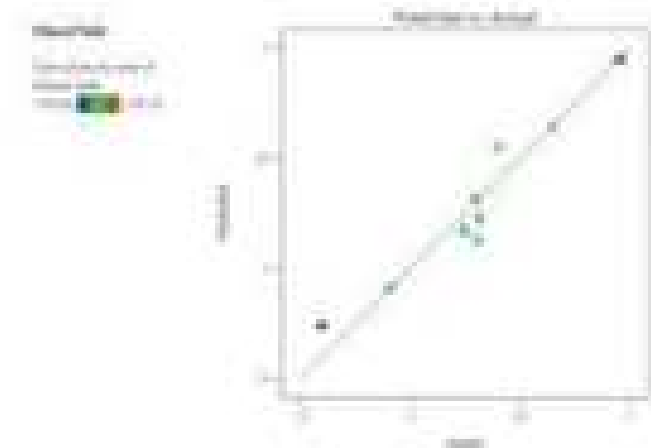


Figure.1 Comparison Between two yields

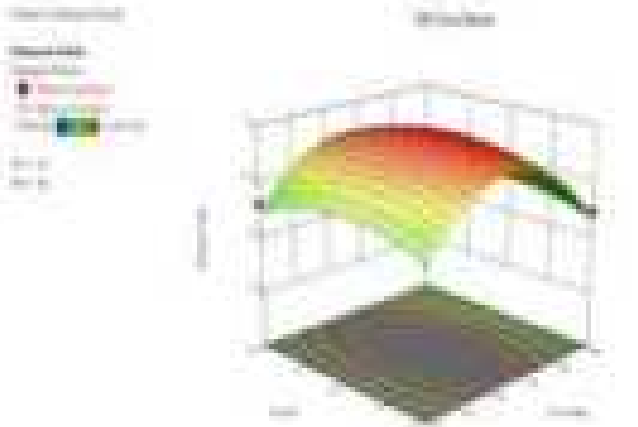


Figure.2 3D representation of actual yield and predicted yield

IV. CONCLUSION

Agro industries are one of the major contributors for environmental pollution and accounts for about 10-15% for pollution. The major advantage of wastes generated from agro industries is that they can be effectively reused and recycled. Nowadays coconut based agro industries is gaining importance as because value added products from coconut is increasing day by day. In parallel the waste generated from coconut based agro industries is also increasing in a considerable level, which needs to be addressed at this juncture to reduce the level the pollution. The treated coconut water contains an affordable amount of nutrients such as Total Suspended Solids (TSS), Total Dissolved Solids (TDS), total nitrogen, phosphorus, potassium, total sugar, reducing sugars and total lipids for bioethanol production. The results showed relatively high levels of total potassium at 1072 mg/L, total solids at 884 mg/L, total acidity at 45. mg/L, total sugar at 1.60%, total nitrogen at 0.12%, total phosphorus at 10.8 mg/L, total lipids at 0.09 mg/g and dissolved oxygen at 23 mg/L. And this study it was evident that, treated coconut water can be potentially used as a raw material for production of bio-ethanol. Favourable conditions for bioethanol production from M/W were found to be 37.5oC and 5.5 pH. Since the yield of bio-ethanol is low when compared to cane molasses, future research can be done on supplementation with nutritionally rich substrates like fruit wastes, lignocellulosic biomass, starchy residues, etc., and this will pave way to enhance the bio-ethanol production from M/W.

REFERENCES

(1)Ping, L., & Chen, Y. (2011). Conversion of paper sludge to ethanol by separate hydrolysis and fermentation (SHF) using *Saccharomyces cerevisiae*.

- (1)Hansen and Bowness, 1994, 1088-1089, <https://doi.org/10.1016/j.biombio.2011.01.004>
- (2)Ollaghi, A., & Boland, N. E. (2017). Optimization of ethanol production from microwave alkali pretreated rice straw using statistical experimental designs by *Saccharomyces cerevisiae*. *Industrial Crops and Products*, 101(1), 334-341. <https://doi.org/10.1016/j.indcrop.2017.12.033>
- (3)Oppenfel, T., & Bach, L. (2017). Production of bioethanol from effluents of the dairy industry by *Kluyveromyces fragilis*. *New Biotechnology*, 38(6), 607-613. <https://doi.org/10.1016/j.nbt.2017.11.017>
- (4)Ferreira, R.L., F.M. Rodrigues, R.P. Louro, and M.L. Castejo. 2007. "Total free sugars, oil and total phenolic content of stored coconut (Cocos nucifera L.) water." *Philippine Journal of Science* 136 (2):109
- (5)CAMPOS, C.F., F.E.A. SOUZA, J.V. COELHO, and M.B.A. OLIVEIRA. 1996. "Chemical composition, enzyme activity and effect of enzyme inactivation on flavor quality of green coconut water 1:7." *Journal of food processing and preservation* 20 (6):487-500
- (6)Kumbhar, D., N.R. Yadav, V.R. Karmar, B.R. Karmarhari, and P.M. Gundgavi. 2023. "Determination of physico-chemical characteristics of waste coconut water." *International Journal of Agricultural Sciences* 18 (2):0084-009
- (7) López Zamora, L., J.A. González Calderín, E. Trujillo Vázquez, and E. Belabes Reynoso. 2010. "Optimization of ethanol production process from cassava starch by surface response." *Journal of the Mexican Chemical Society* 54 (4):198-203.
- (8)Shrivastava, S., G. Padhyaja, S. Moorthy, M. Sajeev, and J. Sheriff. 2011. "Process optimization for bioethanol production from cassava starch using novel eco-friendly enzymes." *Biomass and Bioenergy* 35 (2):801-809
- (9)Jackson, J.C., A. Gordon, G. Witzend, K. McCook, and R. Boffe. 2004. "Changes in chemical composition of coconut (Cocos nucifera) water during maturation of the fruit." *Journal of the Science of Food and Agriculture* 84 (7):1049-1052.

Co-pyrolysis of Plastic Waste and Lignocellulosic Biomass for High-Recovery Fuel Oil

J. Gnanajothi

S. Karthikeyan

S. Sriramanjan

P. Vijayakumari

B. Ramesh

Teaching Assistant,
CPHE, AIICRI,
TNAC, Coimbatore
jgnanajothi@gmail.com

Professor and Head,
CPHE, AIICRI,
TNAC, Coimbatore
skarthikeyan@aiicri.in

Professor and Head,
DIAGE, V.O.C.ACRI,
V.O. Cheluvannur,
TNAC, Kottaiam
srsriramanjan@voca.ac.in

Associate Professor,
DIAGE, AIICRI,
TNAC, Coimbatore
vijayakumari@aiicri.in

Professor and Head,
DIAGE, AIICRI,
TNAC, Coimbatore
bmeselakumar@aiicri.in

18

Abstract

Upgradation of bio-oil is essential to achieve its utilization as fuel oil and increase its feasibility. Co-pyrolysis of biomass with plastic waste is carried out to enhance the value of bio-oil. Based on the characterization of Micro plastic waste (HDPE, PP, LDPE) and lignocellulosic biomass (wheat, red gram stalk, Mitha dalma, and coconut husk) are carried at 25/75, 50/50, 75/25, 100/0 to recover fuel oil at four different reaction temperatures i.e., 400, 450, 500, and 550 °C in a laboratory set up. The product yields like solid residue, fuel oil, and non-condensable pyro-gas are noted. The maximum fuel oil is recovered with a ratio of 75 % micro plastic waste and 25 % biomass. FT-IR analysis of fuel oil produced from co-pyrolysis of biomass and plastic waste shows the presence of alkanes/alkenes and aromatic hydrocarbons.

Keywords: Biomass, Bio-oil, Co-pyrolysis, Fuel-oil, Plastic waste

INTRODUCTION

Petroleum resources are depleting and non-renewable. This creates a need to alternative renewable energy sources to meet the energy crisis. Bio-oil has several environmental advantages over fossil fuels as a clean fuel. Bio-oils are carbon (CO₂/CERs) neutral and it can also generate CO₂ credits. However, the potential for direct substitution of bio-oil for petroleum fuels and chemical feedstock is limited due to their high viscosity, high water and ash content, low heating value, low miscibility with H₂ fuels, instability, and high corrosiveness [1]. Technical developments and fiscal progress have turned out to be inconsistent with the pervasive consumption of natural resources. Especially, the plastic consumption due to its ease of practical application, low cost, and high resistance

has increased extremely. As a result of that plastics have become an important environmental issue even though they do not generally pose a direct hazard to the environment. Increasing cost and decreasing space of landfills, the traditional methods for the removal of plastic wastes such as landfiling and incineration which cause irreversibly environmental problems do not constitute a viable solution from an environmental standpoint. Instead of using traditional disposal methods, recycling these waste by using advanced technologies to produce energy or chemicals is certainly a better way to today's advanced technology. Since bio-oil and petroleum fuels have an identical chemical nature, it is not considered for petroleum fuel substitution [2,3]. Co-pyrolysis will add to the economic advantage of decreasing the waste volume as very little or no spent is landfills, save energy and cost in waste treatment, and solve several environmental issues and area occupancy of landfills. Co-pyrolysis will be the best alternative technology for handling biomass and plastic waste in the future and to replace petroleum fuels and conventional waste treatment methods. This also paves to the energy security of our nation and reduces fossil fuel import [4,5,6]. Additionally, a number of key elements of co-pyrolysis, the yields of co-pyrolysis products and the properties of the bio-oil generated, the benefits and drawbacks of the process, the mechanism of co-pyrolysis of plastic and biomass, and the synergistic effects of co-pyrolysis between plastic and biomass are reviewed [7,8]. This concludes the discussion of the role of catalysts in co-pyrolysis and the impact of some operating parameters, most notably the biomass mixing ratio and pyrolysis temperature, on the yields of products from the co-pyrolysis of biomass and plastic [9]. The study's findings demonstrated that co-pyrolysis technology, particularly when applied to waste plastic and

biomass, is a promising technology that can be used to reduce our dependence on fossil fuels, increase a country's energy security, and manage waste effectively. It is also simple and efficient. Hence, co-pyrolysis is necessary to give a liquid product that can be used as a liquid fuel in various applications.

II. METHODOLOGY

Based on availability and research articles, screening of Agave/cactus biomass (viz., red grain stalk (field level residual), coconut husk (plantation crop residual), sorghum (agro-industrial waste) and *Melinis dactyloides* (straw crop) are enumerated and characterized to co-pyrolysis with mixed plastic. The collected mixed plastic waste contains High-Density polyethylene (HDPE), Low-Density polyethylene (LDPE), and Polypropylene (PP). Physico-chemical characterization of the sample is performed based on ASTM procedure.

The testing setup is a stainless-steel cylindrical container of 1 mm thickness with a thermal conductivity of $15 \text{ W m}^{-1} \text{ K}^{-1}$. The diameter of the setup is 5.5 cm and the height is 4 cm. The reactor is provided with two holes with a diameter of 5 mm on the lid for the exit of pyrolysis gas and condensed to recover the fuel oil.

III. RESULTS AND DISCUSSION

Physico-chemical characterization such as moisture content (MC), Volatile content (VC), fixed carbon (FC), ash, lignin (L), hemicellulose (HC), and cellulose (C) of selected biomass were assessed (Table 1).

Table 1: Physicochemical characterization

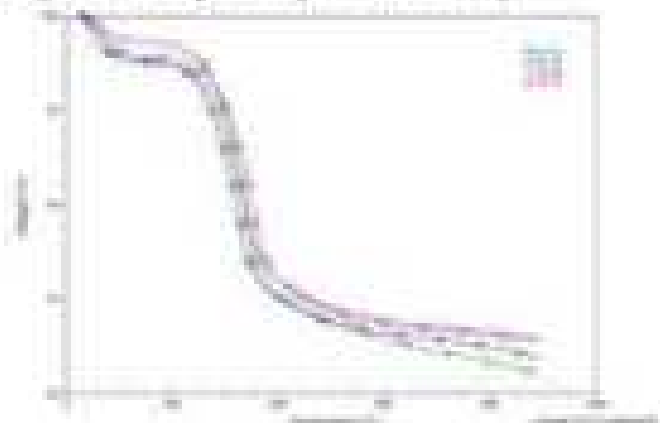
Feed stock	MC %	VC %	FC %	ash %	L %	HC %	C%
BGS	6.6	62.3	15.6	15.5	31.8	22.6	43.4
CH	6.1	67.6	17.6	8.9	40.8	18.7	29.9
SD	6.3	76.2	14.2	3.3	33.1	31.6	48.7
MPW	7.4	81.1	9.2	2.3	27.4	26.4	47.2
MPSW	0.3	84.3	1.8	3.6	-	-	-

The average moisture content of the selected biomass varied from 6.1 to 6.6 %, plastic waste do not absorb the moisture, and mixed plastic waste moisture content was found to be 0.3 %. The average volatile content of the selected biomass varied from 62.3 to 81.1 % and plastic waste were found to be high with 84.3 %. The average fixed carbon content of the selected biomass varied from 8.2 to 17.6 % and plastic was found to be less at 1.8 %. The average ash content was found to be 2.3 to 15.5 %. The average lignin, hemicellulose, and cellulose content of biomass are 31.8, 24.6, and 29.9 % respectively. The results show that the selected samples can be utilized for pyrolysis conversion [10,11].

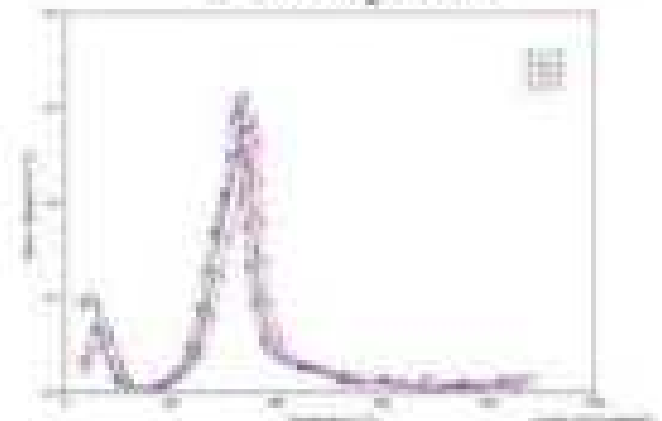
These results indicate that biomass pyrolysis can be identified as three phases, i.e., moisture evaporation, main

devolatilization, and continuous devolatilization; the reference sample has a slight influence on the weight loss of the biomass sample; different biomass samples can lead to the same trend of its weight-loss curve, but a different amount of weight loss. Fig. 1. shows the TGA graphs for various samples produced at two different temperatures.

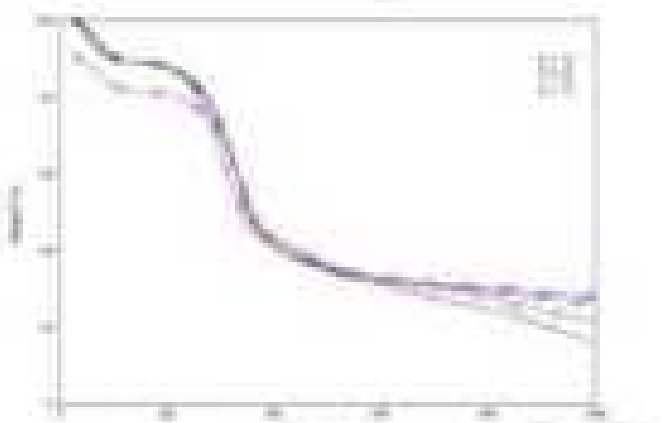
Differences in thermodegradability among the biomass and plastic waste samples were evident, although all samples displayed an initial mass loss up to 110°C attributed to water loss, and a final steady decrease in weight above the peak temperature of heating.



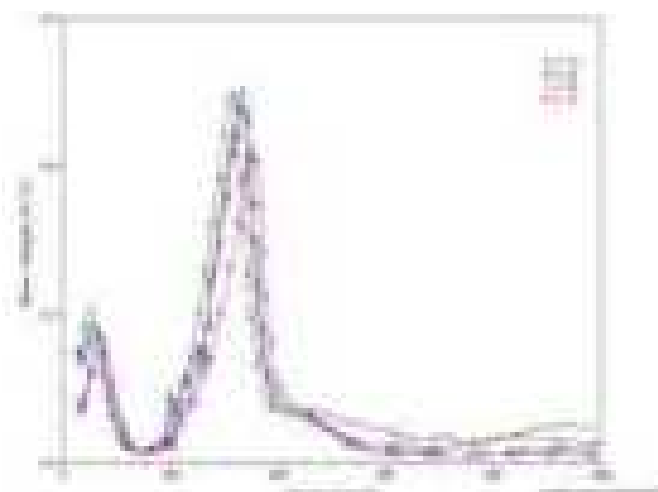
a. TGA - Redgrass stalk



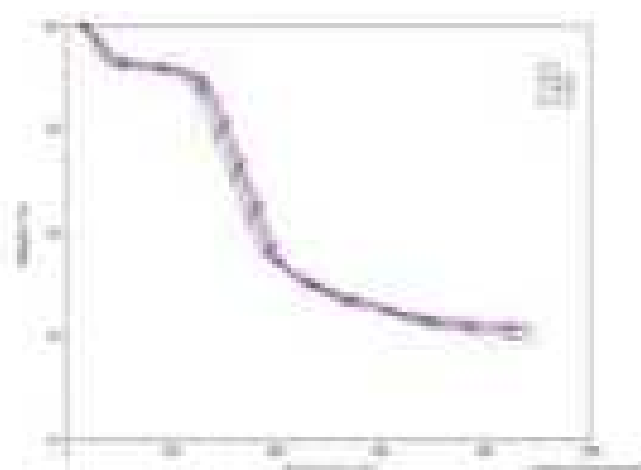
b. DTG - Redgrass stalk



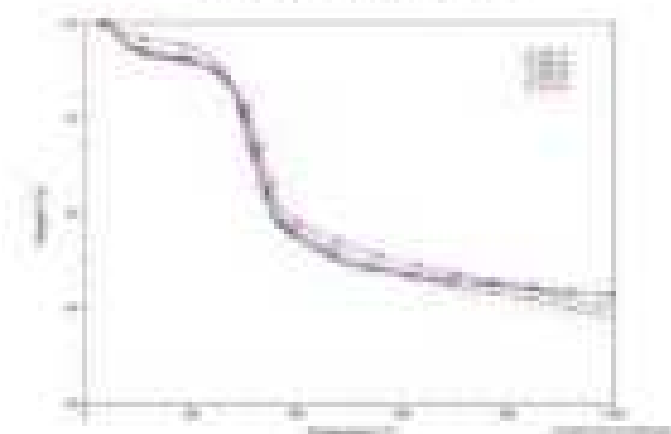
c. TGA - Coconut husk



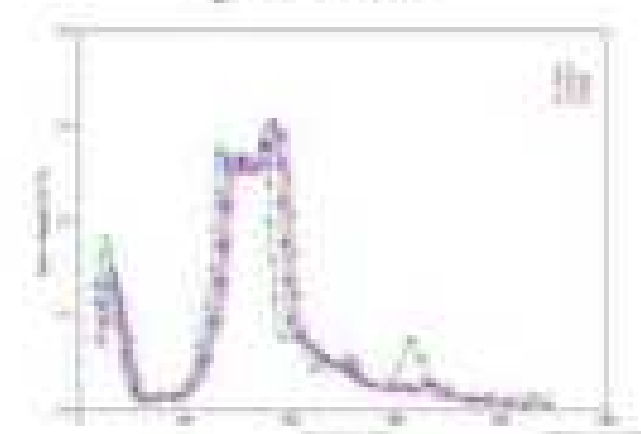
d. DTG - Coconut husk



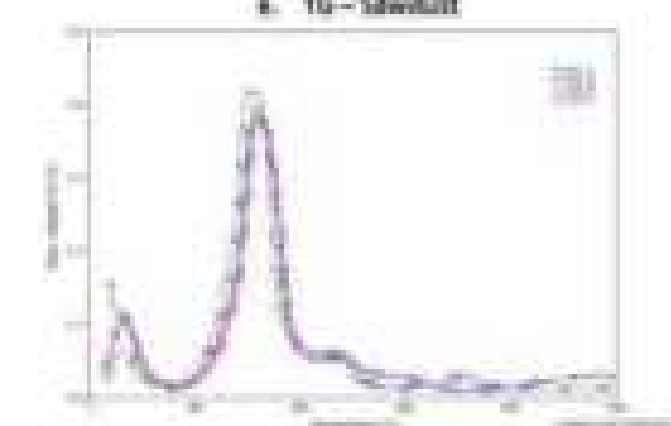
e. TG - Molle Apple



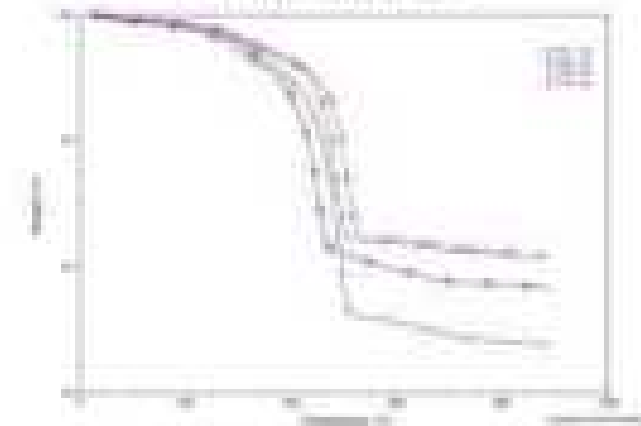
f. TG - Sawdust



g. DTG - Molle Apple



h. DTG - Sawdust



i. TG - Mixed plastic waste

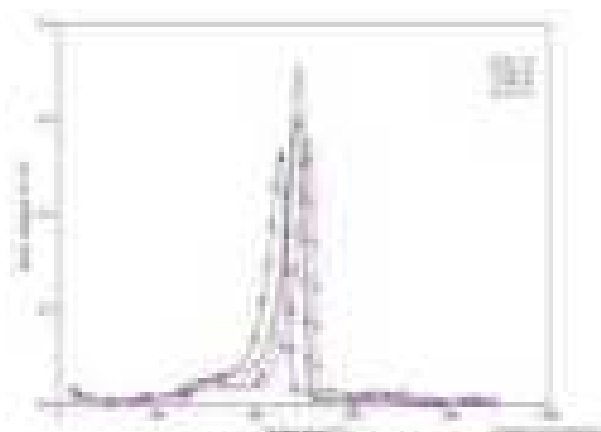


Figure 1. DTG - Mixed plastic waste

Figure 1. DTG and DTG of the selected sample.

The degradation of lignocellulosic biomass under inert conditions can be broken down into three distinct stages. The first stage is dehydration ($<100^{\circ}\text{C}$), followed by active pyrolysis ($150\text{--}400^{\circ}\text{C}$), and, lastly, passive pyrolysis ($>400^{\circ}\text{C}$) [12]. The steepest stage of weight loss in the curve can be attributed to the removal of the volatile in the biomass. Therefore, the reaction has completely evaporated by 150°C for each heating rate. Similar studies acknowledge this same occurrence for lignocellulosic materials. The main changes were between 200 and 500°C . Biomass at 400 and 450°C showed a strong weight loss above 400°C , respectively. It can also be inferred from the results that, for more complete carbonization of the feedstock, it is not only feedstock type, pyrolysis temperature, and heating rate are important [13]. To ensure the complete release of volatiles, holding the peak temperature at the end of the pyrolysis process is recommended to ensure the complete release of volatiles.



Figure 2. Laboratory set up.

Based on the characterization of Mixed plastic waste (HDPE, PP, LDPE) and Lignocellulosic biomass, combinations of Mixed plastic waste and biomass were arrived at 25:75, 50:50, 75:25 (80:20 to recover fuel oil). Laboratory studies on fuel oil production from mixed plastic waste with biomass were carried out at 3 different reaction temperatures 400 , 450 , and 500°C in a laboratory setup (Fig.2).

Different product yields like solid residue and fuel oil are measured. The remaining value is accounted as non-condensable pyro-gas [15]. The fuel oil production from the feedstock quantity and quality of the final product varied from optimizing and changing the different process parameters for this experiment. In this experiment, processing parameters such as reaction temperature and inert gas flow rate were chosen. For all trials, the feed rate of 1 kg h^{-1} of plastic waste was used. Different product yields like solid residue and fuel oil are measured (Fig.3). The heating rate can be defined in many terms in various pyrolysis research. In a fast pyrolytic process, waste plastic will be cracked and vaporized quickly once entering the pyrolytic reactor. The hydrocarbon vapor temperature was close to 500°C , which is higher than the baseline temperature of 110°C .

Plastic start with random cracking during which a series of hydrocarbon products such as non-condensable gases (C_1 to C_4) will be produced. In these cases, the heating rate means the rate of temperature increasing per unit time (10°C/min during the contacting time, which can range from $400\text{--}500^{\circ}\text{C}$). However, in practice, the most convenient way to control the heating rate is to control the heating load to the pyrolytic reactor at a given heating rate. It has been found that the heating rate has both effects on the pyrolysis reaction rate and the effect on the distribution of fuel oil yield [15].

This part of the experimental studies aimed to experimentally examine the effect of temperature on the pyrolysis process and the product distribution and to identify how temperature triggered the cracking of the plastic at these under experimental conditions [16,17].

Based on the literature, the reaction temperatures selected for the experiments were 400 , 450 and 500°C to study their influence on the yield of these and pyrolysis products.

From the experimental results, the optimum value for the parameters Table 2.

The fuel oil yield in percentage from plastic waste with biomass in the different combinations is found to be in the range of 43 to 78 (25:75); 49 to 68 (50:50) and 58 to 77 (75:25). The fuel oil yield from plastic and biomass are found to be 58 to 68 and 51 to 35% , respectively.

Table 2. Parameters for experiment

Sample	N ₂ flow, L/min	Temp., °C	Fuel Oil yield, %
PW/SD (75:25)	15	400	77.2
PW/SD (75:25)	15	400	71.5
PW/CH (75:25)	25	400	72.1
PW/MD (50:50)	15	520	66.1

Co-pyrolysis of plastic waste with sawdust increased the fuel oil yield by 10 % whereas Motor diesel declined by 10 %.

Co-pyrolysis offers an increase in fuel oil yield compared to pyrolysis yield[18]. Products from the co-pyrolysis process are suitable for thermal energy and energy production and can also be utilized in chemical industries[19]. The addition of biomass affected the yield. The research confirms that saw dust with plastic waste yields a better result than other combinations[20,21].

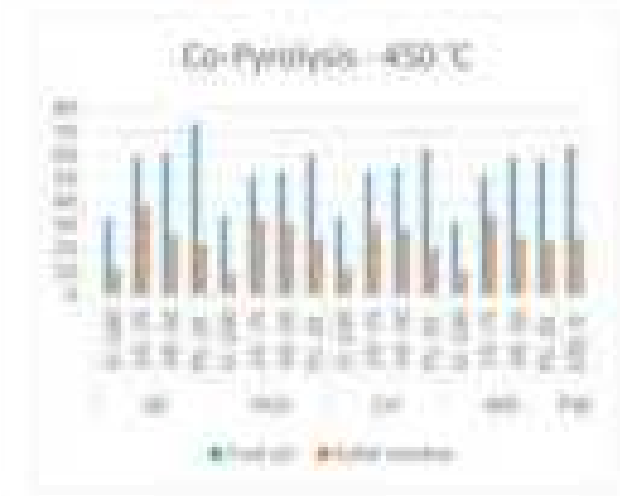
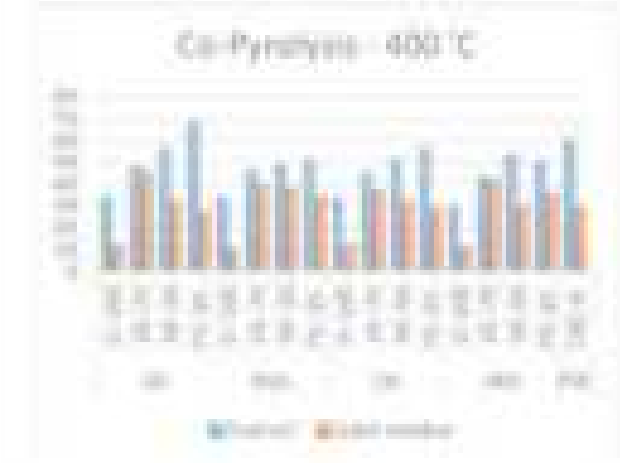


Figure 3: Yield details on co-pyrolysis

The FT-IR and GC-MS graph of fuel oil produced from co-pyrolysis of plastic waste with biomass are analyzed to study the compounds present in fuel oil. From the FT-IR results, it is inferred that the major compounds present in the fuel oil are C -C bonds, alkanes, C -H bonds, methyl and methylene groups, aromatic C -O bonds, ketone and aldehyde groups, C -O bonds, acids, O -H bonds, phenols and alcohols[22,23]. The FT-IR and GC-MS graph of fuel oil produced from co-pyrolysis of plastic waste with saw dust are represented in Figure 4 and 5.

Thirty compounds were identified from GC-MS results. The compounds are 1-Octadecane (7.09%), 1-Heptadecane (4.34%), 1-Pentadecane (0.09%), 1-Tetradecane (4.73%), 1-Nonadecane (4.71%) and aliphatic hydrocarbons (alkanes and alkenes). The GC-MS results confirm the upgrade the quality of pyrolytic oil/ fuel oil [25].

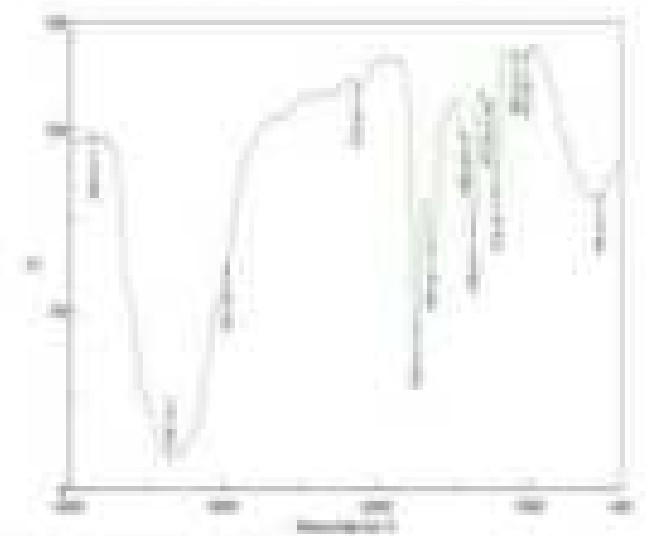


Figure 4: FT-IR spectrum

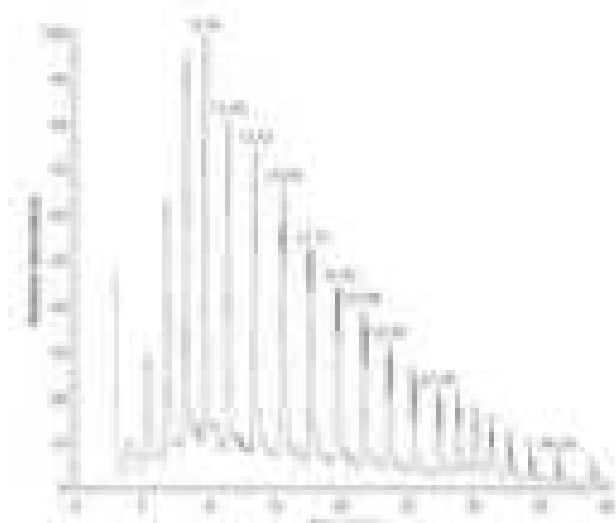


Figure 5b: GC-MS- graph

10. CONCLUSIONS

Co-pyrolysis of waste plastic and solid biomass should be developed with an emphasis on producing value-added goods and alternative fuels. This will lead to a synergistic solution for waste management, mitigating climate change, and protecting the environment. Co-pyrolysis offers effective waste management and the use of carbon flow wastes to assist ensure that fossil fuels have a circular destiny.

Based on the characterization of Mixed plastic waste (HDPE, PP, LDPE) and lignocellulosic biomass (sawdust, red grain stalk, *Melinis dactyloides* and coconut husk), combinations of Mixed plastic wastes and biomass arrived as 25:75, 50:50, 75:25:100:0 to recovery fuel oil. Laboratory studies on fuel oil production from mixed plastic waste with sawdust, red grain stalk, *Melinis dactyloides* and coconut husk were carried out at four different reaction temperatures viz., 400, 450, 500 and 550 °C in a laboratory set up. Different product yields like solid residue and fuel oil were recovered. The remaining value is accounted as non-combustible pyro-gas. The highest fuel oil yield obtained from saw dust, red grain stalk, *Melinis dactyloides* and coconut husk was 74.40(WPC), 65.58(WPC), 62.56(WPC) and 66.56(WPC) with mixed plastic waste. The maximum fuel oil was recovered with a ratio of 75 % mixed plastic waste and 25 % biomass. The solid residue was varied as 16 to 21 %. FT-IR analysis of fuel oil produced from co-pyrolysis of biomass and plastic waste shows the presence of alkanes and alkenes in the range of 2900-2850 cm^{-1} and aromatic hydrocarbons (700-600 cm^{-1}).

Co-pyrolysis of waste plastic and solid biomass has been studied to improve synergistic impact, lower activation energy or energy consumption, enhance product yield, choose product transformation, minimize or eliminate toxic emission, and address expanding waste management challenges. As far as we now know, there are still a lot of

challenges that we must consistently on and get past in the future. There are lots of chances for engineers and researchers in these areas.

Acknowledgements

We thank the Department of Renewable Energy Engineering, AFCCRI, Tamil Nadu Agricultural University, Coimbatore, and Indian Council of Agricultural Research - ARRP on LAAI - LRT scheme for the support rendered to carry out this research.

REFERENCES

- [1] Ana-Christina Ionescu, Linda Sandstrom, Glen G.W. Hurrell, *Biomass Co-pyrolysis of waste biomass and plastic waste in both analytical and pilot scale*, *Journal of Analytical and Applied Pyrolysis* (2008), 134-10 (2008) (aug. 2018) 25-33.
- [2] Dharithra, A. and G. Arun, *An Overview of Biomass Pyrolysis*, *Energy Sources*, 24 (2002) 471 - 482.
- [3] Wang, F., Harris, K. G., Lu, T., & Gupta, A. K. Co-pyrolysis of waste plastic and solid biomass for synergistic production of biofuels and chemicals-A review, *Progress in Energy and Combustion Science*, 84 (2021) 100899.
- [4] Oual Tylem, Doud Boura Umar, Ayra Eren Pinar, *Bio-oil production via co-pyrolysis of almond shell as biomass and high-density polyethylene*, *Energy Conversion and Management*, 78 (2016) 764-770.
- [5] Li Shoudan, Xuei Chen, Ailin Liu, Li Wang, Guangyan Yu, *Co-pyrolysis characteristics of biomass and Shennong coal*, *Bioresour Technol*, 179 (2017) 414-420.
- [6] Meera Van de Velde, Jan Baeyens, Anke Baeyens, Bart Janssens, Raf Dewil, *Fundamentals, Kinetics and mechanism of the biomass pyrolysis reaction*, *Renewable Energy*, 151 (2019) 132-34.
- [7] Bhuvaneshwari et al. (2019), *Crop residue burning in India: policy challenges and potential solutions*, *International journal of Environmental research and public health*, MDPI publishers, ISSN: 16604693.
- [8] Hassan Ibrahim et al. (2019), *Bio-energy production from rice straw: A review*, *Insper publishers*, ISSN: 2575-8578.
- [9] He Li et al. (2019), *Catalytic upgrading of biomass-derived to value-added products*, *International journal of chemical engineering*, Hindawi publishers, ISSN: 16076133.
- [10] Javier Telleche Azana et al. (2019), *One-step synthesis of CuO-ZnO efficient catalyst for biodiesel production*, *International journal of chemical engineering*, Hindawi publishers, ISSN: 16076133.
- [11] Lohani Pratik et al. (2016), *Catalytic pyrolysis of biomass and polymer waste*, *MDPI publishers*, ISSN: 8120619.

- [12] Le Zhang et al. (2014), GC-MS and FT-IR analysis of the bio-oil with the addition of ethyl acetate during cracking, *Frontiers in petroleum*, ISSN: 161389
- [13] Lijun Zhou et al. (2017), Catalytic pyrolysis of rice husk by mixing with rice straw: Characterization of bio-oil and its rheological behavior, *Plastics publishers*, ISSN: 385394
- [14] Lihua Chen et al. (2019), Bio-oil upgrading by cracking in two stage heated reactors, *AIChE press publishers*, ISSN: 303317
- [15] Martin Garsowet et al. (2020), Sustainable rice straw management, *Springer open publications*, ISBN: 873-2-0310-12733-8
- [16] Mohamed Ota et al. (2018), Production of bio-oil from agricultural waste, *Anal biochem publishers*, ISSN: 21611489
- [17] Mohamed Saffar Khan et al. (2011), Bio-oil from pyrolysis of rice husk, *Indian journal publishers*, ISSN: 0078-3838
- [18] Mohammed Alshaban et al. (2012), Catalytic pyrolysis of rice husk for bio-oil production, *Assigned manuscript of journal of analytical and applied chemistry*, ISSN: 0163-2378
- [19] Umar Mahapatra et al. (2016), Production of bio-oil from rice straw, *International journal of chemical and environmental engineering*, *WARP publishers*, ISSN: 22634360
- [20] Purnendu et al. (2016), Bio-oil production and upgrading: New challenges for membrane applications, *Woodhead publishers*, ISSN: 1878-009-100431-7
- [21] Sergio Capareda et al. (2017), Batch pyrolysis of acid treated rice straw and potential products for roofing and bio-oil production, *Springer publishers*, ISSN: 1366-855X/17060-4
- [22] Weiya Zhang et al. (2019), Upgrading of biomass and upgrading of bio-oil: A review, *MIRI publishers*, ISSN: 24137370
- [23] Sybilah Fardous et al. (2020), Comparison of liquefaction and pyrolysis method used for bio-oil production from various biomass, *KNIE publishers*, ISSN: 251373407
- [24] Yi Chen et al. (2019), Recent developments in heterogeneous biomass catalyst for pyrolysis strategies for the optimization of bio-oil quality and yield, *Elsevier publishers*, ISSN: 136189
- [25] Zubair Malik et al. (2018), Using GC-MS to analyze bio-oil produced from pyrolysis of agricultural waste: A bio-oil contains drying oil, coffee and eucalyptus saw dust in the presence of 5% Hydrogen and Argon, *Journal of analytical and bio analytical techniques*, ISSN: 1555-8873



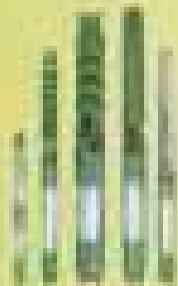
Screwwell Submersibles
Single Phase Domestic Pumps
Single Phase Jet Pumps



Pumps you can rely on



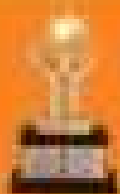
Agricultural Monoblocks
Openwell Submersibles
Pressure Boosting Systems



SPECIAL FEATURES

- Saves Electricity • More discharge of water • Best after sale service
- Sturdy Build • Low maintenance • Ability to operate in low voltage

- Agriculture • Domestic • Industries • LT Park • Construction • R.O Plant
- Boiler-Feed Applications & Pressure Boosting • Solar Pumps



Winner of TOP RANK AWARD IN 2015
- For receiving First Prize in
National Energy Conservation Award
for Four Consecutive years

11 TIMES EXPORT
AWARD WINNER



Wide range of R.O. and water Pump Sets



ISO 9001:2008 Certified



More than
3500 Models

AQUASUB ENGINEERING + AQUAPUMP INDUSTRIES

Thudiyalur Post, Coimbatore - 641034. Ph: 0422-2642484, Fax: 0422-2642128

E-mail : marketing@aquagroup.in, Website : www.aquagroup.in

® Registered Trade mark of Aquasub Engineering & Aquapump industries for Texmo & Aquatex brand Products only

A Novel Battery Charging Method for Plug-in Fuel Cell Hybrid Electric Vehicle

Dr. Kashyap Pruthiakar

CREAT, Ume Munda, Pune
Email: kpruthiakar@creativemunda.com

Bhaskar Kumar Dore

CREAT, Ume Munda, Pune
Email: bkdore@creativemunda.com

Dr. Jagjit Sagar Barhate

CREAT, Ume Munda, Pune
Email: jbarhate@creativemunda.com

Girish Kamble

CREAT, Ume Munda, Pune
Email: gkamble@creativemunda.com

Abstract

The plug-in fuel cell hybrid electric vehicle (PFCHV) possesses the features of a battery EV and fuel cell hybrid electric vehicle (FCHV). The PFCHV provide a remarkably efficient driving range due to the integration of distinct energy sources. However, the range depends on the capacity of the energy sources, such as the battery and hydrogen storage tank. Considering the Indian geographical scenario, there is a lack of hydrogen refueling stations and technology challenges. However, at present, in India, the technology development and installation of EV battery charging infrastructure enabled with fast charging are rapidly growing to make EVs feasible by solving a range anxiety issue. Therefore, in this paper, a novel battery charging methodology is proposed for PFCHVs from the grid, DC, fast charging station to achieve the desired range. This method may help to optimize the battery size and hydrogen fuel tank capacity without affecting the range of PFCHVs.

Keywords: Battery charging, driving range, FCHV, Plug-in EV, Public charging station

1. INTRODUCTION

Somadays every megacity throughout worldwide severely facing air pollution due to the tailpipe emission of fossil fuel-based vehicles. Therefore, the adaptation of new energy vehicles has become a main research interest for major vehicle manufacturers and academic institutions [1-3].

At present, several alternate energy source-based vehicles, such as battery-operated, hybrid, and fuel cells are commercially available for transportation. The hydrogen fuel cell hybrid electric vehicle (FCHV) has

immense potential for high energy efficiency and zero emission [4]. Compared to the battery electric vehicle (BEV), the FCHV can achieve a more extended range with a lower refueling time [4]. However, when the FCHV operates in transient states, such as start-up, acceleration or climbing, the response rate of the generation of required electrical energy from the fuel cell is behind the rate of changing load [5]. As a result, the fuel cell system is not able to generate the required power precisely for the above-mentioned operating conditions. A fuel cell system (FCS) is unable to store the energy generated during the regenerative braking due to its unidirectional power output flow capability [6]. These parameters may affect the FCHV driving range, reliability, economy, and durability [7]. Therefore, to overcome the above-mentioned issue the FCHV is mostly equipped with an ultra-capacitor or battery as an auxiliary energy storage system [8-9]. Such an arrangement of multiple energy sources increases the complexity of the power source unit of the vehicle and it requires an additional energy management methodology (EMM) to make the sources operate efficiently, reliable, and stable [10-11]. The EMM manages each energy source and distributes the power effectively according to the demand for power. As a result, improves system efficiency, fuel consumption, and longer lifetime of the energy sources and FCHV [12]. Usually in FCHV, the battery capacity is low as compared to pure EV and it is charged through the fuel cell and braking energy. Thus the primary function of the battery is to provide extra power in start-up conditions and unable to help to extend the driving range due to its capacity. Furthermore, in plug-in fuel cell hybrid electric vehicle (PFCHV) the auxiliary battery support for achieving extended driving range. Here, the battery has a higher capacity and it is charged from the AC mains.

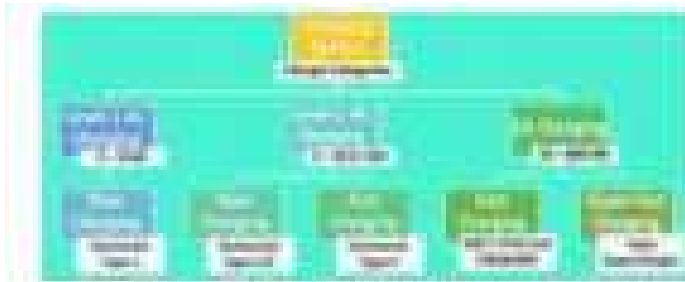


Figure 3: Generic Classification of Charging Stations

Currently, there are approximately 11,000 public EV chargers in India, with 6,000 being slow chargers and the rest being fast chargers. However, it is projected that by 2030, India will require at least 1.2 million public EV chargers to support the growing number of EVs on the road. Moreover, only two hydrogen refilling stations have been installed in India in comparison to two battery charging stations [17]. There is a huge difference in the installation of battery charging and hydrogen refilling station which demonstrates that in India the FCHEV will take a longer time to gain popularity as compared to BEV. Hence, FCHEV has with additional battery and has it charging with different sources such as onboard charging, AC charging, and DC fast charging. Therefore, the subsequent section discusses the proposed battery charging scheme for the FCHEV.

III. PROPOSED CHARGING METHODOLOGY FOR FCHEV

In the FCHEV, a hybrid vehicle system combines both electric charging capabilities and hydrogen fuel cell technology operating using a combination of both systems to power the vehicle. Figure 4 demonstrates the proposed charging methodology for the FCHEV. This comprises a proton exchange membrane fuel cell (PEMFC) system which charges the battery and a DC-DC converter is used to maintain the required voltage in the power distribution unit. An in-house developed on-board charger (3.3kW) is used to charge the battery from the AC source as well as a DC charging station such as CCS (shown in Figure 4). Subsequently, the lithium-ion battery is connected to the motor control unit to drive the motor on-demand operating conditions.

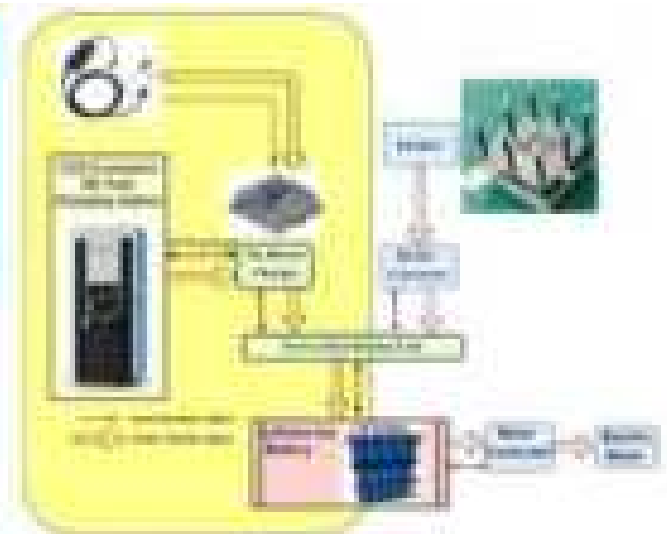


Figure 4: Block diagram of Proposed Charging methodology for FCHEV

By combining both electric charging capabilities and hydrogen fuel cell technology, hybrid vehicles can benefit from the advantages of both systems. The electric charging system provides zero-emission electric driving capability and the ability to charge the battery from an external power source. The hydrogen fuel cell system offers a longer driving range and quicker refueling time compared to relying solely on a battery. On the other hand, Country such as India already has the infrastructure ready for a CCS-based DC Fast charging system, while it will take many years of time for an easily available hydrogen refueling system.

Most of the users need a day of maximum 100 km for daily use, while most or better they need a higher range such as 400km or so on for travelling. The proposed methodology will take care of both variation.

This combination allows hybrid vehicles to be more versatile and efficient, utilizing the strengths of both electric and hydrogen technologies to reduce emissions and address range limitations.

The next section discusses the experimental results of the proposed methodology.

IV. RESULTS AND DISCUSSION

This section describes the developed hardware setup to validate and check the effectiveness of the proposed novel battery charging methodology for the FCHEV. The experimental setup is shown in Figure 5 and it comprises, an AC power supply (AC6000), High voltage (HV) power supply (60047A), electronic load (EP7046A), oscilloscope (DS90), CAN communication tool, current probe (70030), developed on-board charger (OBC), and power selector unit.



Figure 5: Experimental Setup

The in-house developed OBC specifications are given in Table 1. The developed experimental setup simulates the operation of the proposed charging methodology discussed in Section III. Here, the HV power supply is used to match the voltage level of the CCS fast charging station and the AC power supply is used to represent the grid power supply. The power electronic unit consists of the AC and DC contactors to enable or disable the charging from the requested power source, i.e., AC source or DC fast charging station. An electronic load is used to mimic the behaviour of the actual EV battery and it is configured as 100V and 15 A output voltage and current, respectively. Finally, the CAN tool is used for transmitting and receiving signals and communicating with other devices.

Table 1: The On-Board Charger Specification

Parameters	Specification
AC Input Voltage	160 Vac-260 Vac
AC Input Current	15 Arms (max)
DC- Input Voltage	280 Vdc-450 Vdc
Output Power	3.3 kW (nominal)
Output Voltage	60 Vdc-150 Vdc
Output Current	12 A Max
Mounting	Inside in Vehicle
Communication	CAN

Using the development setup, the experiments were performed for the following cases:

- Case-A: Battery Charging from AC source.
- Case-B: Battery charging from HV source (simulate the CCS-based charging).

For Case-A the obtained experimental results were by enabling AC power source, demonstrated in Figure 6. Here, the output current is changed from 5 A to 30 A and again to 5 A to check the charge performance. Moreover, in the zoom view of Figure 7 the input AC voltage and current are aligned in phase which represents that the charger operates at unity power factor.



Figure 6: Experimental results for the Case-A

Similarly, the experiments performed for Case-B is to validate the proposed charging methodology at different charger output currents and the results are shown in Figure 7(a)-7(b). The obtained results show excellent performance at HV input.

In summary, extensive experiments have been performed for both cases, i.e., Case-A and Case-B. From the results analysis, it is observed that the developed charger and

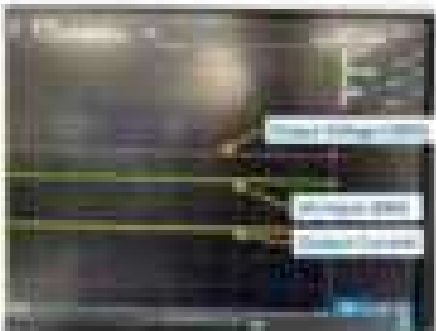


Figure 7 (a): Experimental result for Case-B at 5A output current

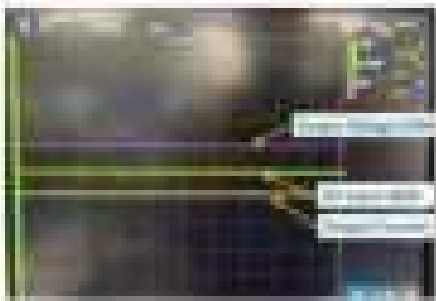


Figure 7 (b): Experimental result for Case-B at 10A output current

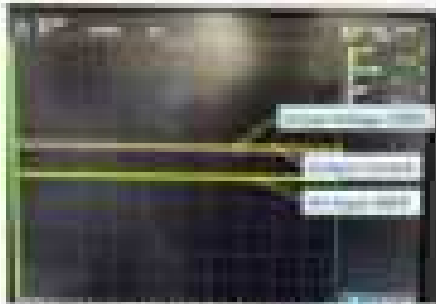


Figure 7 (c): Experimental result for Case-B at 20A output current

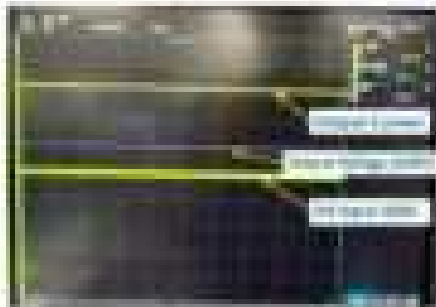


Figure 7 (d): Experiment result for Case-B at 30A output current

setup configuration can maintain the required charging strategy to validate the proposed methodology.

Finally, the conclusions are presented in the next section.

V. CONCLUSIONS

This paper proposed a novel battery charging method for FCHEV in an Indian scenario. Here, the battery can be charged from the GLS or other DC-fast charging stations or AC source. This method will save hydrogen on board and help increase the vehicle range. The proposed work's practical feasibility and effectiveness are validated through developed hardware and obtained experimental results. From the experimental result observations, it is found that the proposed charging methodology can be implemented in actual FCHEV to increase the driving range of the vehicle by availing the facility of the charging station.

Acknowledgements

This work is supported by the CREAT, UNO MINDA Limited, Pune, Maharashtra, INDIA. The authors would like to express profound gratitude to Mr. Lingaraj Bandiwad (Hardware Testing Manager) and his team for helping in performing the experiments and hardware setup development.

REFERENCES

- [1] Liang, L., Gong, P. Urban and air pollution: a multi-city study of long-term effects of urban landscape patterns on air quality trends. *Sci Rep* 10, 19018 (2020).
- [2] H.R. Gurjar, Khairul Basirah, Ajay Singh Nigam, Air pollution trends over Indian megacities and their local-to-global implications. *Atmospheric Environment*, Volume 142, 2016, Pages 475-481, ISSN 1352-2310.
- [3] Shukla, Shashna P., and Vignesh V. Mha. "1 A review on current status and future scope of hydrogen fuel cell technology in India and across globe." *Advanced Ceramics and Applications* (2021).
- [4] Guo, J., Li, M., Hu, Y., et al. Challenges and developments of automotive fuel-cell hybrid power systems and control. *Sci China Technol Sci* 2019,62(7):1-25.
- [5] Farhatkhah B. Combining a proton exchange membrane fuel cell (PEMFC) stack with a Li-ion battery to supply the power needs of a hybrid electric vehicle. *Renew Energy* 2019;130:114-24.
- [6] Jang, M., Choimura, M., Aggelos, V.D. Design and implementation of digital control in a fuel cell system. *IEEE Trans Ind Inf* 2012;8(2):1179-86.
- [7] Almusall, P., Tumbel, S.H., Almusall, H. et al. The effects of driving patterns and PEM fuel cell degradation on the lifecycle assessment of hydrogen fuel cell vehicles. *Hydrogen Energy* 2020;45(1):1793-808.
- [8] Taghizadeh, M.M., Jafari, M. Degradation analysis of dual-ended mode PEM fuel cell at the low and high thermal and pressure conditions. *Int J Hydrogen Energy* 2019;44(16):4985-91.
- [9] Samsuri, M.A., Ghoshani, B., Abdelhalek, O., et al. Comparative study of energy management strategies for hybrid proton exchange membrane fuel cell front wheel drive electric vehicle. *J Power Sources* 2020;462:123167.
- [10] Yao, L., Li, J., Chong, M., et al. Multi-mode control strategy for fuel cell electric vehicles regarding fuel economy and durability. *Int J Hydrogen Energy* 2014; 39(3):2174-89.
- [11] Baka, A.P. Batteries and supercapacitors for electric, hybrid, and fuel cell vehicles. *Proc IEEE* 2007;95(4):506-20.
- [12] Han, Y., Li, Q., Wang, T., et al. Multisource coordination energy management strategy based on SOC consensus for a PEMFC-battery-supercapacitor hybrid energy. *IEEE Trans Veh Technol* 2017;67(1):296-307.
- [13] Zhou, X., Wang, L., Zhou, Y., Fan, B., Wang, B., Wang, T., and Yin, X. 2022. Energy management strategies for fuel cell hybrid electric vehicles: Classification, comparison, and outlook. *Energy Conversion and Management*, 279, p.116179.
- [14] Dufourn, IEA Global EV. "Catching up with climate ambitions." IEA, Paris, France (2021).

- [15] Anayag, N. "Handbook of electric vehicle charging infrastructure implementation." National portal of India (2021).
- [16] <https://indiaenviroment.in/1002025-charging-of-electric-vehicle>
- [17] <https://www.adea.com/car-guide/hydrogen-cars-in-india>

Carbon Capture and Storage Potential in India

Bariya prabhasaran M

ME engineering design
PMT college of technology
Email: 12madh@pognit.ac.in

Rishith Y

ME engineering design
PMT college of technology
Email: 12madh@pognit.ac.in

Dr.Prabir T

Professor
PMT college of technology
Email: prabir@pognit.ac.in

Abstract

A developing country such as India which is one of the most populous and rapidly industrializing country, now faces a compelling need to reduce its carbon emissions and contribute to climate change mitigation efforts. The needs for carbon storage in India are driven by several factors, including the country's heavy reliance on coal for energy, expanding affluence, and increasing emissions from industrial sectors. These factors contribute to rising CO₂ levels, air pollution, and climate-related vulnerabilities. Therefore, India must prioritize strategies to mitigate emissions, which can be achieved with the help of carbon capture and storage techniques. This paper explores the specific needs and methods for carbon storage in India. The paper also stresses the importance of reducing greenhouse gas emissions, particularly carbon dioxide (CO₂), and emphasizes the unique challenges and opportunities that India encounters on its path to sustainable carbon management. The topic of carbon storage is covered in detail, including both technical and natural options. Afforestation and reforestation initiatives are examples of nature-based solutions that can be used to boost the carbon sequestration in forests, wetlands, and agricultural fields. Also investigated as ways to improve terrestrial carbon storage are sustainable farming methods and soil carbon sequestration. Technology-based strategies like Carbon Capture and Storage (CCS) are also taken into consideration. The study discusses the difficulties of implementing CCS technology widely in India as well as the promise of these technologies in capturing CO₂ emissions from industrial processes and power production facilities. This paper also discusses about the importance of integrated strategies that combine nature-based solutions, technological advancements, and policy measures to achieve effective CCS in India. It further emphasizes the need for international collaboration, research, and investment to support India's efforts in addressing its carbon storage needs while achieving global climate goals.

Keywords: carbon capture, carbon storage, carbon sequestration and afforestation.

1. INTRODUCTION

Over the past five decades, India, a nation with a rich array of cultural traditions and a booming economy, has experienced extraordinary growth and development. The swift urbanization and industrialization that have driven this shift have propelled India into the spotlight as a major economic force, but this expansion has come at a price: the country's carbon content has significantly increased CO₂.

For India, industrialization has been a double-edged sword. On the one hand, it has aided in the evolution of technology and served as an engine for economic growth, pulling millions out of poverty. However, it has also resulted in a variety of environmental and sustainability issues, with the rise in carbon emissions being of particular concern. In-depth analysis of the causes, effects, and potential mitigation measures of India's rapid industrialization and its rising carbon content is provided in this paper.

A planned programme of economic self-sufficiency and increased industrialization defined India's post-independence era. However, India started moving towards economic liberalization and globalization in the early 1990s, which led to a surge in industrial growth. Along with services, the manufacturing sector emerged as a key engine of the Indian economy, greatly boosting GDP and employment. In India, the energy-intensive industrial sector, which includes the steel, cement, and chemical industries, has been a significant source of carbon emissions.

Significant amounts of carbon dioxide (CO₂) have been released into the atmosphere as a result of the burning of fossil fuels, particularly coal, for the production of electricity and industrial activities [1-5]. In addition, the expansion of the Automobile sector and the rise in demand for energy-hungry equipment has led to an

emissions in emissions from the household and transportation sectors.

Many Indian cities air quality has gotten worse along with the rise in carbon emissions. The release of CO₂ coupled with particulate matter, sulphur dioxide (SO₂), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) has led to significant air pollution (12-14). Poor air quality has a significant negative impact on public health, increasing the risk of cardiovascular disease, respiratory illnesses, and shorter life spans. India's growing carbon footprint has a substantial impact on climate change worldwide. A variety of climate-related risks, such as extreme weather occurrences, shifting rainfall patterns, and increasing sea levels, are present throughout the country. These effects have an influence on infrastructure, water resources, and agriculture, providing significant obstacles to India's sustainable growth.



Fig 1. Global per Capita CO₂ emissions as of 2021(15)

India has produced almost 1 to 2 tonnes of CO₂ in the year 2021 which can be seen in the above figure. To reduce its CO₂ production India has taken several policy measures and mitigation strategies. The National Action Plan on Climate Change (NAPCC) outlines a comprehensive framework to address climate change, including the development of renewable energy sources, energy efficiency measures, and afforestation programs. India has also made ambitious commitments to expand its renewable energy capacity. While India's efforts to mitigate carbon emissions are commendable, they face numerous challenges. Energy access for a growing population, energy security, and the economic costs of transitioning to low-carbon technologies are some of the key hurdles. Balancing industrial growth with environmental sustainability is an ongoing challenge, but also an opportunity to leverage green technologies, create jobs, and secure a more resilient future (11).

The relationship between India's fast industrialization and the rise in carbon footprint is a complicated and multifaceted problem. Also, India

contributes to almost 7.2% of CO₂ in the entire world (12).

As we shift toward cleaner energy systems and reduce emissions in high-impact sectors like construction and transportation, people are actively striving to extract carbon from the atmosphere. We are adjusting our approaches to building, consumption, travel, and energy generation. Techniques like CCN demonstrate our ability to collaborate with the natural environment in addressing the climate crisis.

While industrialization has helped millions of people live better lives and contribute to economic progress, it has also had negative effects on the environment, including an increase in carbon emissions, air pollution, and climate vulnerabilities (14). India is attempting to reconcile industrial expansion with sustainability through new policy measures in light of these difficulties. The nation's capacity to negotiate this complex terrain and carry a route towards sustainable development that is both economically successful and environmentally responsible will determine the trajectory of India's carbon content in the future, which is in accordance with SDG (Sustainable Development Goals) 13, which deals with the climate action that advocates to reduce the net zero carbon production.

1. STEPS AND SIGNIFICANCE CCN

Climate change is primarily caused by an increase in greenhouse gases, particularly carbon dioxide (CO₂), in the Earth's atmosphere. These gases trap heat, which causes global warming. By capturing and storing CO₂ emissions, carbon storage devices help to reduce the amount of CO₂ released into the atmosphere, so halting the rise in global temperatures.

Carbon Capture and Storage (CCN) is a technology designed to reduce the release of carbon dioxide (CO₂) emissions into the atmosphere, primarily from industrial processes and power generation (1-4). It is an essential component of efforts to combat climate change by mitigating greenhouse gas emissions. Generally, CCN is performed in 3 steps: capture, transportation, and storage (1-10).

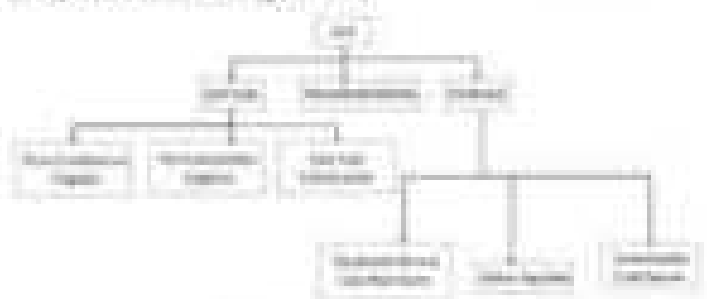


Fig 2. Steps in CCN

1.1 Capture

It refers to the initial step in the CCS process where isolation and capture of CO₂ is performed. The source of CO₂ can be any emission source ranging from large thermal power plants to any small-scale industries. The primary goal of this step is to separate CO₂ from the other gases produced in combustion or industrial processes so that it can be transported and stored separately. It can be further classified as follows:

Pre-Combustion Capture: This method involves capturing CO₂ emissions after the combustion of fossil fuels. It uses chemical solvents or sorbents to absorb CO₂, separating it from other emissions, hence called as absorption process. The chemical solvents or sorbents are used to remove CO₂ from the gas stream. These substances pick out CO₂ from the flue gases and absorb it. The CO₂ is then released for transport and storage after the solvent or sorbent, which is now laden with CO₂, is removed.

Pre-Combustion Capture: In this process, fuel is first converted into a gas mixture of hydrogen and carbon monoxide (syngas) through gasification process. CO₂ is captured from the syngas before combustion, from which CO₂ is separated with the help of chemical solvents.

Oxy-fuel Combustion: Oxy-fuel combustion involves burning fuel in a mixture of oxygen and recycled flue gas. This results in a concentrated stream of CO₂ that can be captured more efficiently.

1.2 Transportation

The act of carrying collected carbon dioxide (CO₂) from the capture location, such as an industrial facility or power plant, to the storage site, where it will be safely held to prevent its escape into the atmosphere, is referred to as transportation. To deliver CO₂ to the storage location safely and effectively, proper conveyance is required.

This is often achieved through pipelines, similar to natural gas pipelines, or by transporting CO₂ in specialized tanks or ships. The transportation method depends on the distance between the capture source and the storage site. To deliver CO₂ safely and effectively to the storage location, proper conveyance is required.

1.3 Storage

After transportation, it becomes necessary to store CO₂ to prevent its release into the atmosphere. The most commonly used storage method is geological storage (13, 14), where deep holes are dug and CO₂ is dumped into them. There are three main types of geological storage sites:

Depleted Oil and Gas Reservoirs: These are previous oil and gas fields where hydrocarbon reserves have been depleted. These reservoirs can be filled with

CO₂, which will safely store the CO₂ while displacing any leftover hydrocarbons.

Saline Aquifers: These are sediment-rocked porous rock areas that are located deep beneath. Saline aquifers can be used to inject CO₂, which is stored in the gaps between the rock grains.

Unmineralized Coal Seams: In some circumstances, CO₂ can be injected into unmineralized coal seams, where it is either trapped inside the coal or adsorbed onto the coal's surface.

1.4 Significance of CCS



Fig. 1. Carbon storage by site with various efficiencies (quantification in Gt CO₂e)

CCS is considered an important technology for mitigating carbon emissions from various sources. From the above graph we can infer that introducing CCS can decrease the amount of CO₂ present in the atmosphere by a great margin. Some other significances of CCS are shown as follows:

- **Carbon Reduction:** In industries with few other options, CCS can drastically reduce CO₂ emissions from industrial operations and power plants.
- **Negative Emissions:** By extracting more CO₂ from the atmosphere than is created, some CCS systems, such as Bioenergy with Carbon Capture and Storage (BECCS), can provide net-negative emissions (15).
- **Carbon Management:** CCS aids in controlling carbon emissions from sectors like heavy industries that are difficult to entirely decarbonize.
- **Energy Security:** CCS can enable the continued use of fossil fuels while reducing their environmental impact by trapping CO₂ from their combustion.

However, CCN also faces challenges such as planning, location, cost, infrastructure, maintenance and most importantly public acceptance. Also, it is necessary to provide long-term safety and security of stored CO₂ in a critical consideration. These issues are being addressed by improving CCN technology research and development, making CCN a more practical weapon in the battle against global warming.

3. TYPES OF CCN

Techniques for capturing and storing carbon dioxide (CO₂) emissions from various sources are known as carbon storage techniques, carbon sequestration, or carbon capture and storage (CCS). These methods aid in lowering atmospheric CO₂ levels, which play a significant role in climate change and global warming.

Some of the most commonly used carbon capture and storage techniques are listed below.

3.1 Geological Storage

a. Carbon Capture and Storage (CCS): CCN involves capturing CO₂ emissions from industrial processes or power plants and injecting them into underground geological formations, such as depleted oil and gas reservoirs, saline aquifers, or deep coal seams. This prevents the CO₂ from escaping to the atmosphere.



Fig 4. Schematic of CCS (CCN)

b. Enhanced Oil Recovery (EOR): In some cases, CO₂ is injected into oil reservoirs to increase oil recovery. This is a form of CCN where the CO₂ is stored underground while also aiding in energy production.

3.2 Terrestrial Carbon Storage

a. Afforestation/Reforestation: Planting trees in areas where they did not previously exist or have been removed. Trees absorb CO₂ during photosynthesis and store it in their biomass and in the soil.

b. Reforestation: Restoring previously forested lands that have been deforested or degraded. This can help increase carbon storage in ecosystems.

c. Soil Carbon Sequestration: Implementing practices that enhance carbon storage in soils, such as no-till agriculture, cover cropping, and agroforestry. Healthy soils can store significant amounts of carbon.

d. Wetland Restoration: Wetlands are highly effective at sequestering carbon. Restoring or conserving wetland ecosystems can help store CO₂ in vegetation and soil.

3.3 Oceanic Carbon Storage

a. Ocean Fertilization: This involves adding nutrients (such as iron) to the ocean to stimulate the growth of phytoplankton, which absorb CO₂ during photosynthesis. However, this technique is controversial due to potential ecological risks.

b. Ocean Alkalinity Enhancement: Increasing the alkalinity of seawater can enhance its capacity to absorb and store CO₂, but this approach also has potential environmental impacts.

3.4 Mineralization

Accelerating the natural weathering process of certain minerals (e.g., olivine) can capture CO₂ directly from the atmosphere and store it in the form of stable carbonates. This approach is considered a long-term and secure method for removing and storing CO₂. Mineralization is often referred to as "mineral carbonation" or "enhanced weathering."

3.5 Direct Air Capture (DAC)

A cutting-edge technology in the area of carbon capture and storage (CCS) is direct air capture (DAC). Instead of capturing carbon dioxide (CO₂) emissions at their source, such as industrial sites or power plants, it is designed to remove CO₂ straight from the atmosphere. DAC is a promising strategy to combat climate change by decreasing the atmospheric concentration of CO₂. An emerging technique called direct air capture has the potential to be very helpful in addressing climate change and achieving net-zero emissions. It shows potential as a useful instrument in the larger portfolio of climate mitigation methods as research and development in DAC proceed.

3.6 Biomass Energy with Carbon Capture and Storage (BECCS)

This combines biomass energy generation (e.g., from crops or forestry residues) with CCN to achieve negative emissions. CO₂ is captured during biomass combustion and then stored underground. The technique helps in a greater magnitude to curb the biomass as a

3.7 Carbon Mineralization

This involves turning CO₂ into stable mineral forms through chemical reactions, making it a long-term and secure storage method.

3.E. Biomergy with Carbon Capture and Storage (BECCS)

BECCS combines biomass energy production with CCS to capture CO₂ emissions from the combustion of biomass. It is considered a negative emissions technology.

3.F Deep Ocean Storage

This technique involves storing CO₂ at great depths in the ocean, where the CO₂ is turned into a dense liquid-like form due to high pressure and low temperature.

Each of these carbon storage techniques has its advantages and challenges, and their effectiveness can vary depending on factors such as geological conditions, ecosystem health, and the availability of resources. Sometimes a combination of these techniques may be necessary to effectively reduce carbon emissions and combat climate change. Additionally, it's important to consider the environmental and social implications of these techniques when implementing them on a large scale.

4. POSSIBLE TECHNOLOGIES IN COIMBATORE

India, like many countries, is exploring various Carbon Capture and Storage (CCS) technologies to reduce carbon dioxide (CO₂) emissions from industrial processes, power generation, and other sources. The suitability of specific CCS technologies in India relies on various elements such as the type of emissions, geographical location, and available resources [3, 8].

Some of the technologies that have a lot of scope in India are Biomergy with Carbon Capture and Storage (BECCS), Carbon Separation, Direct Air Capture (DAC) and Geological storage [20]. To gauge the potential of CCS in a city like Coimbatore, it's essential to begin by comprehending the city's geological positioning.

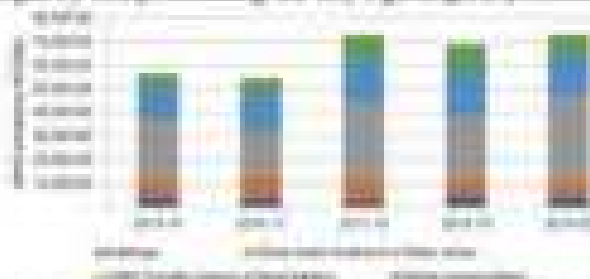


Fig 3. Trend of GHG-CO₂ emissions from 2017-20 (35)

Coimbatore is the third largest city in Tamil Nadu, with a population of about 1.85 million covering an area of 257 sq. km. The city is situated on the banks of the river Noyyal surrounded by the Western Ghats.

The city is renowned for its production of water pump sets and a wide range of engineering goods, including textile machinery, automotive components,

minors, chemicals, as well as steel and chemical handy products.

The city boasts a beautiful supply of hills, woodlands, rivers, and wildlife. The Western Ghats within the district are the source of rivers like Bharani, Noyyal River, Alpan, and Siruvani, which serve as critical water sources for drinking and irrigation purposes for both the city's residents and local farmers. The district's forests cover an expansive 691.46 square kilometers within its total area of 7,433.72 square kilometers.

The need for CCS technologies in Coimbatore becomes necessary as the city produces almost 70 tonnes of CO₂ per year as of 2020, which can be observed from the above graph. By the close of this century, Coimbatore is projected to experience a rise in the average maximum temperature of 3.3°C and an increase in the average minimum temperature of 3.4°C. Additionally, there is an expected uptick in rainfall of up to 8.2% by 2050, accompanied by a growing occurrence of brief, high-intensity rainfall events (GZ). Also, the rapid industrialization after the COVID-19 pandemic has led to further increase in CO₂ emissions much greater than the recorded values.

For a city like Coimbatore, boasting several advantages in geological location as well as a plethora of industries, the most suitable CCS methods would be Carbon Separation/Pre-combustion Carbon storage with major focus on Afforestation and Reafforestation, and the second-most suitable method would be Biomergy Carbon Capture and Storage (BECCS).

It also becomes necessary to understand about these methods in detail to further support this claim.

4.1 Carbon sequestration

Carbon sequestration, involves the process of extracting carbon from the atmosphere and securely storing it, represents just one of the numerous strategies employed in the fight against climate change. Halting further warming of the Earth's atmosphere is a substantial and collaborative endeavor by humanity to curtail CO₂ emissions. Carbon sequestration is widely acknowledged as a pivotal means of extracting carbon from the Earth's atmosphere.



Fig 4. A working Scheme of Carbon Sequestration (47)

It's crucial to highlight that approximately 41% of the carbon dioxide released by human activities remains within the atmosphere, a major contributor to global warming. Carbon sequestration serves as a means to both mitigate and manage additional emissions that would otherwise exacerbate planetary warming, as illustrated in the provided figure.

Carbon sequestration is generally possible in two basic forms: biologically or geologically sequestration. Additionally, even while it is processed artificially through a variety of techniques, sometimes it also occurs naturally on a massive scale.

4.1.1 Biological carbon sequestration

When carbon is stored in the environment, it is called as Biological Carbon sequestration. This includes the so-called "carbon sinks," which include soil, meadows, oceans, and other bodies of water in addition to trees. Another name for this is "indirect" or passive method of sequestration.

4.1.1.1 Forests

Woodlands and forests are thought to be among the greatest natural systems for storing carbon. During photosynthesis, CO₂ binds to plants and exchanges it for oxygen as a purifying emission. Also, each plant has its own capacity to store CO₂.

Forests absorb twice as much carbon as they release, while other vegetative types like grasslands and rangelands (fields, prairies, shrublands, etc.) are thought to store an additional 25% of the world's carbon emissions, as illustrated in the below graph where different type of forest absorbs different rates of CO₂.

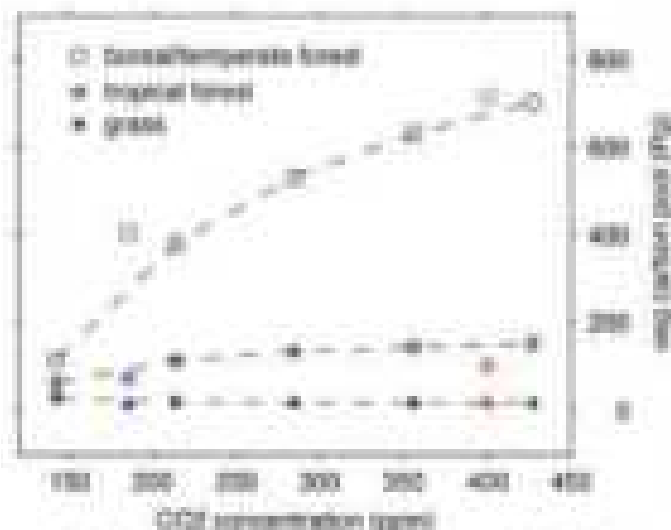


Fig 1. Simulated Carbon Storage through Carbon Sequestration for different types of vegetations (34)

Thus, maintaining these natural habitats is essential to guaranteeing that carbon sinks efficiently absorb CO₂. The main forests in the natural process are

coniferous and invasive agriculture, together with deforestation.

4.1.1.2 Soil

Carbon can be sequestered and preserved as carbonates in bays, peat, and swamps. As CO₂ combines with various mineral elements like calcium or magnesium over thousands of years, these carbonates accumulate. Carbon eventually escapes the planet, though not for an exceptionally lengthy duration—more than 70,000 years, in some situations.

4.1.1.3 Oceans

Massive reservoirs of water and aquatic habitats are excellent CO₂ absorbers. They take up an additional 25% of the CO₂ that is sent into space by the earth's atmosphere. The ocean's upper layers contain the majority of this carbon. However, too much may acidify the water, endangering the biodiversity below — another reason to reduce the amount of carbon in our atmosphere.

4.1.2 Geological carbon sequestration

It happens whenever carbon is sequestered in materials like rocks or subterranean geological formations. This mechanism, which is primarily artificial or "direct," is a useful means of effecting emissions from human activities like building and manufacturing. As a result, it's also mostly technological, with new developments demonstrating more efficient large-scale carbon sequestration. They generally include:

4.1.2.1 Graphene Production

CO₂ is a basic ingredient needed in the synthesis of graphene. Though restricted to specific contexts, it plays a significant role in the manufacturing of everyday technological goods like computer chips and cell phones.

4.1.2.2 Engineered Molecules

By absorbing carbon from the atmosphere, molecules are able to reshape molecules into new substances. In actuality, this might offer a productive means of producing raw materials and lowering atmospheric carbon.

4.2 Scaling of Carbon Sequestration

Researchers are still trying to master technologies that would enable large-scale carbon sequestration in a short amount of time. Any activity that captures carbon dioxide emissions will hasten our transition to carbon neutrality. The easiest method to scale up carbon capture is to support the expansion of our natural environment while promoting what is already in place.

Large-scale carbon capture will be made possible by avoiding, refining, or reducing of agricultural

land. Pollution removal from our lakes, seas, and oceans will also aid in this process.

4.1 Bioenergy Carbon Capture and Storage (BECCS)

A new strategy called bioenergy with carbon capture and storage (BECCS) combines the production of bioenergy with carbon capture and storage (CCS) to attain zero-carbon electricity (CO₂) emissions. It entails removing CO₂ from the environment by capturing more CO₂ from the atmosphere than is released.

Anaerobic digestion of organic solid waste is one of the mechanisms for sustainable development since it permits both the energy-efficient disposal of solid waste and the use of biogas (34). After combustion a lot of CO₂s is released into the atmosphere, due to burning of organic materials.

The CO₂ emissions are captured before they are released into the atmosphere after the bioenergy has been produced. Pre-combustion capture, post-combustion capture, and other capture technologies are suitable method can be used to accomplish this. Then the captured CO₂ is transported to the storage location from the place of capture using suitable transportation methods. Also, the type of storage is dependent upon the geographical location, cost etc.

The sustainability and economic viability of BECCS are essential to its success. The price of biomass feedstock, the effectiveness of energy generation, and the environmental effects of biomass sourcing are all factors to be taken into account. The main benefit of BECCS is its capacity to remove CO₂ from the environment on a net basis, helping to balance out emissions from other sources. However, the technique has issues with cost-effectiveness, energy efficiency, and sustainably sourced biomass.

8. SUITABLE FAUNA FOR CARBON SEQUESTRATION IN COASTAL TRE

It is important to select the species of fauna on trees for carbon sequestration. The selection depends on geographical location, soil fertility, moisture, land availability, cost, maintenance and security.

Some of the selective species of fauna will have a comparatively high carbon sequestration. Timber wood trees are good in carbon sequestration and valuable for the market needs too. From agricultural lands can be suggested with these types of trees like teak and mahogany.

It is also important to select it based on the geographical conditions and a sample representation of carbon sequestration using trees is shown in the fig 9 below.

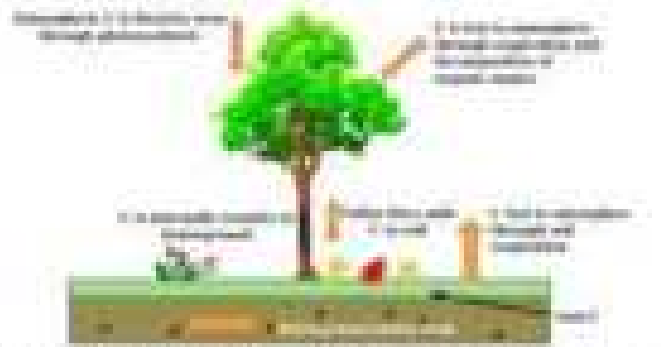


Fig 9. The process of carbon Sequestration through trees (34)

It is necessary to understand that different species of plants/ trees have different capacities to store CO₂ within it. Some trees along with their CO₂ storing capacity for each tree are given in the table below.

Table 1. Various trees with their CO₂ equivalent storage

Scientific name	Common name	CO ₂ Eq
<i>Ficus benjamina</i>	Weeping Fig	70.02
<i>Alnus scholaris</i>	Scholar's Tree	11.18
<i>Phormia officia</i>	White Frangipani	76.47
<i>Delonix regia</i>	Flame Tree	68.77
<i>Nyctanthes arbor-tristis</i>	Kalamb	69.04
<i>Ficus microcarpa</i>	Laurel Fig	69.95
<i>Chlorocarya arborea</i>	Indian Mahogany	69.68
<i>Phoenix dactylofera</i>	Date Palm	67.13
<i>Grassia arborea</i>	Silver Oak	69.24
<i>Reynoldsia regia</i>	Royal Palm	69.44
<i>Calligonum canaliculatum</i>	Hardhead tree	76.49
<i>Eucalyptus sp.</i>	Eucalyptus	67.99
<i>Mimosa sp.</i>	Humbug	76.06
<i>Mimosa citrifolia</i>	Spanish Cherry	69.35
<i>Albizia leonardus</i>	Santa	68.94

<i>Cassia florida</i>	Indian Laburnum	70.68
<i>Phyllanthus emblica</i>	Indian Gooseberry	68.30
<i>Dalbergia sissoo</i>	Indian Rosewood	65.36
<i>Ficus religiosa</i>	White Fig	64.03
<i>Ficus religiosa</i>	Sacred Fig	63.54
<i>Morus alba</i>	White Mulberry	68.74
<i>Lagerströmia speciosa</i>	Prickly Pear	70.04
<i>Pithecellobium porphyreum</i>	Copper pod	111.71
<i>Moringa oleifera</i>	Drumstick tree	68.79
<i>Banksia acuminata</i>	Dwarf white acacia tree	65.09
<i>Banksia vulgaris</i>	Banksia	54.77
<i>Sesuvium portulacastrum</i>	Portulacastrum	454.11
<i>Azadirachta indica</i>	Neem tree	70.05
<i>Podium guianense</i>	Guava	57.08
<i>Ficus elastica</i>	Rubber Tree	70.42
<i>Mangifera indica</i>	Mango	57.08

From the above table we can find the combined CO₂ Equivalent of the above ground and below ground biomass carbon storage in various tree species. *Pithecellobium porphyreum* and *Sesuvium portulacastrum* shows the maximum CO₂ Equivalent in terms of biomass carbon capture and storage.

Carbon sequestration in different parts of tree follows a sequence, with the bole storing the most in the early stages, followed by the branch, root, and bark. In later stages, the sequence changes to bole, root, branch, and bark. In the case of bark, carbon sequestration increases with age, and at 50 years, each tree was found to store 332.88 kg of carbon in the bole, 80.82 kg in the branches, and 80.88 kg in the roots.

Teak has the highest capacity for carbon sequestration among trees in India. This is the finding of a study conducted by the Gujarat Ecological Education and

Research (GUER) to prepare a hierarchy of local trees in India that can reduce the carbon dioxide content of the atmosphere. Carbon dioxide traps heat and is the main villain insofar as global warming is concerned. Carbon sequestration is the process by which carbon dioxide is captured from the atmosphere by trees for long-term storage. In its lifetime, a teak tree with a girth of 10-20 cm can absorb 3.70 lakh tonnes of carbon dioxide from the atmosphere. Teak's common name in India is sagwan while its botanical name is *Tectona Grandis*. It is followed by Neelgai tree which absorbs 2.46 lakh tonnes of carbon dioxide and the Narsa tree with a carbon sequestration capacity of 1.43 lakh tonnes in its lifetime. A total of 23.46 million tonnes of carbon dioxide had been sequestered by trees in non forest areas of Gujarat.



Fig 9. Percentage change in annual carbon sequestration of trees in experimental sites over the control site. [21]

Table 2. Carbon sequestration of various trees (24)

Scientific name of tree	Carbon (kg/tree)	CO ₂ Sequestered (kg/tree)
<i>Albizia julibrissin</i> (silky tree)	9.7024	31.683
<i>Apocynum androsaemifolium</i> (milkweed tree)	2.3788	8.7034
<i>Albizia julibrissin</i> (silky tree)	14.742	52.343
<i>Crucianella</i> (silky tree)	7.8031	25.675
<i>Pithecellobium porphyreum</i> (yellow tree)	6.3264	21.985

Table 2 shows the amount of carbon stored and sequestered by the single tree of five different species from Wadach of YIT University, from that it is clearly known that *Albizia julibrissin* is the species which sequesters carbon in large amount among the five species of trees in their consideration. These five tree species are more commonly known and well grown in most of the areas of Tamil Nadu.

The results indicate that among the species studied, poplars have the highest potential to sequester carbon, followed by Eucalyptus plantations. These

plantations held promise for higher organic matter production in the Terai region.

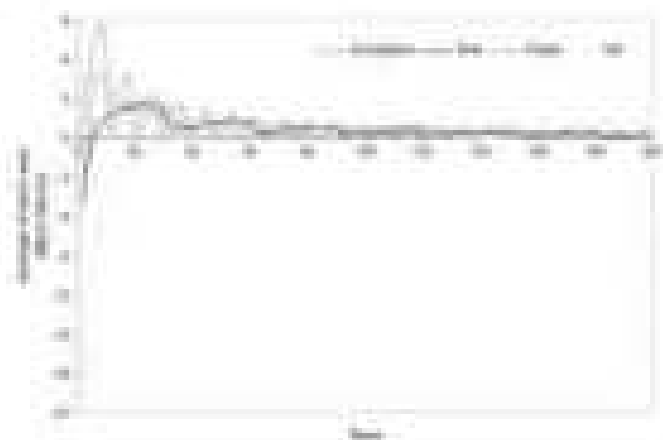


Fig 10. CO₂ uptake with respect to age of trees (29)

This graph shows us that the trees are effective in carbon sequestration only in its early stages of growth. The effective period of carbon sequestration by trees is about 10 to 20 years after which it gets stabilized by aging. *Acacia saligna* is very effective in carbon sequestration with some yielding rate of 10 to 25 years.

8. POLICIES AND MEASURES

In India, the use of CCU capture is still in its infancy. Only a few industries, like steel and refineries, have carried out small-scale carbon capture operations. The National Aluminium Company (NALCO), ONGC, Bharat Heavy Electricals Limited (BHEL), and Andhra Pradesh Power Generation Corporation (APGENCO) are a few enterprises that have started the process of establishing CCN plants (29).

Dattatraya Chavan also announced setting up of a large-scale carbon capture unit (CCU) at one of its plants in Tamil Nadu as a move towards becoming carbon neutral by 2040. From the various technologies available for CO₂ capture, the post-combustion solvent capture and stripping, with some-based pressure swing adsorption systems is the most common.

Typically, CO₂ sequestration projects are expensive and therefore not implemented in isolation in India. A dialogue has been initiated between US-DoE and DGT on clean coal technologies, pre-combustion carbon dioxide (PCO₂) power cycles and carbon capture utilization & storage (CCUS) technologies. One of the notable outcomes of the dialogue is the participation of India in the sustained platform for Accelerating CCUS Technologies (ACT) through which avenues have been generated for possible US - India collaboration (INT, 2020) (18).

The introduction of newer technologies is significantly simplified and made more cost-effective with the presence of government policies and incentives.

There are no policies or directives from government in regards to CCN technology, which makes it hard for several small and medium-scale industries to adopt.

However, it's essential to note that the government's policies and programs related to climate change and environmental conservation indirectly support CCN projects. All climate change related policies advocate about CO₂ reduction which is one of the major objectives of CCN. Hence, incentives can be received for CCN using these government policies.

A general list of Government Policies with regards to climate change, which indirectly promotes the use of CCN technologies are given below:

1. **National Action Plan on Climate Change (NAPCC):** The NAPCC delineates India's approach to tackle climate change challenges. This encompasses initiatives such as the National Mission on Enhanced Energy Efficiency and the National Solar Mission, which indirectly play a role in demonstrating carbon emissions and the demand for CCN.
2. **Renewable Energy Development:** The state of Tamil Nadu has been a leader in renewable energy, especially in the wind energy sector. Expanding of renewable energy sources can help reduce the carbon footprint. When integrated with CCN the net carbon rate can be brought to zero.
3. **Afforestation and Reforestation:** The government of Tamil Nadu, in line with national policies, supports afforestation and reforestation projects to sequester carbon dioxide. The government also offers financial aids to small industries which help in carbon sequestration through reforestation.
4. **Industrial Initiatives:** Some industries in Tamil Nadu, such as BHEL (Bharat Heavy Electricals), which have already implemented CCN technologies as part of their corporate social responsibility (CSR) to reduce the carbon content in the atmosphere to reduce global warming.
5. **Research and Development:** Research institutions and universities in Tamil Nadu receive grants and funding for green and new technologies, which also includes CCN research and development projects.

Additionally, local environmental organizations and research institutions in Tamil Nadu that are involved in CCN projects or related research to reduce CO₂ in the atmosphere are given as follows:

1. **The Energy and Resources Institute (TERI) - Southern Regional Centre:** TERI is a prominent environmental research institution in India. The

Southern Regional Centre, located in Durgam, Karnataka.

2. **Indian Institute of Technology Madras (IIT Madras)**: IIT Madras is one of India's premier engineering institutions. It often engages in research related to sustainable energy and environmental technologies, which includes CCN.
3. **Anna University**: Located in Chennai, Anna University is a leading educational and research institution. It has several departments or centres working on environmental and energy-related projects.
4. **Centre for Climate Change and Adaptation Research (CCCAR) at Anna University**: This centre focuses on climate change research and may have projects related to carbon capture and storage or climate mitigation.
5. **The Nature Conservancy India (TNC India)**: TNC is a global environmental organization that works in India on a range of sustainability and conservation projects, including those that mitigate climate change.
6. **MS, Swaminathan Research Foundation (MSRF)**: MSRF is dedicated to sustainable agriculture and rural development. While their primary focus is agriculture, they also focus on environmental projects and initiatives in Tamil Nadu.
7. **Society for Integrated Development and Environmental Awareness (SIDEA)**: SIDEA is a Tamil Nadu-based local environmental group that promotes environmental conservation and awareness.
8. **The Tamil Nadu State Council for Science and Technology (TNSCST)**: This government organization supports technical advancement and scientific research inside the state. Additionally, they are working on research initiatives pertaining to energy and environmental concerns, such as CCN.

Not only government agencies but several Non-Governmental Organizations (NGOs) are also interested in development and deployment of green and new technologies, like CCN to have a clean environment without any CO₂ in the atmosphere to reduce the risk of global warming. Some of the NGOs which take an active role in this region are mentioned below.

1. **Sivachari**: Based in Coimbatore, Sivachari is a well-known environmental group. Although their main focus has been on revitalizing water bodies and conserving nature, they might have knowledge of or engagement with recent global environmental projects that can utilize CCN.

2. **C&G - Coimbatore Green Alliance**: Coimbatore Green Alliance is a local group dedicated to environmental conservation. While their primary focus may not be CCN, they could have information on climate-related projects in the region.

3. **Paavaiyagi Narayana**: This NGO is engaged in various environmental and social initiatives in Tamil Nadu. While their primary focus is on environmental education and conservation, they might have information on climate change and related projects.

4. **Society for Rural Education and Development (SRED)**: SRED is based in Coimbatore and works on various rural development and environmental projects. They may have insight into local environmental initiatives.

5. **The Nature Conservancy India (TNC India)**: TNC is an international environmental organization with a presence in India. They work on various conservation projects, including climate change mitigation efforts.

In a world where rising carbon emissions is critical, CCN policies and programs are essential tools in the transition to a more sustainable and ecologically conscious future. To drive CCN deployment and achieve the required reduction in greenhouse gas emissions, governments, industries, and stakeholders must work together to assess its technology and approaches carefully to realize.

3. ADVANTAGES AND LIMITATIONS

CCN technology has several advantages as well as limitations when introduced in a developing country like India.

Some of the advantages of CCN can be summarized as follows:

- **Emissions Reduction**: The release of carbon dioxide (CO₂) from a variety of industrial activities, such as India's widely used coal-based power generation, can be greatly reduced by CCN. It can be quite important in assisting the nation in achieving its climate goals.
- **Diverse Energy Sources**: India has a varied energy mix, and CCN is a flexible approach to reducing emissions since it can be used for a variety of energy sources, such as coal, natural gas, and industrial pollutants.
- **Energy Security**: With CCN, the environmental impact of fossil fuels can be minimized while ensuring their continued usage. Given that India's energy infrastructure is still expanding and developing, this is crucial for energy security.
- **Negative Emissions**: In an effort to remove more carbon dioxide from the atmosphere overall, CCN

in conjunction with Bioenergy with Carbon Capture and Storage (BECCS) can produce negative emissions.

- **Job Creation:** In order to promote economic growth, CCS projects can provide jobs in the engineering, construction, and research and development sectors. Which leads to increase in employability rate in the industry.

It is also important to know and understand the limitations of CCS-related projects in the industry. Some of them are discussed below:

- **Cost:** The high implementation costs of CCS provide a major obstacle to its widespread adoption, particularly in developing nations like in India. CCS project funding can be difficult to come by.
- **Energy Intensity:** Energy-intensive CCS may need more energy for capturing carbon and oxidation. Power plants may become less efficient as a result.
- **Regulatory Framework:** India's legislative framework governing the deployment of CCS may require additional development and strengthening to meet concerns related to accountability and prolonged safety.
- **Public Acceptance:** It can be difficult for the public to comprehend and perceive CCS technology, especially when it comes to worries about the safety of subterranean storage and its effects on the environment.
- **Resource Availability:** One important consideration is the lack of suitable storage sites, such as saline aquifers or exhausted oil and gas reservoirs. India must evaluate these sites' suitability for carbon capture and storage (CCS).
- **Competing Priorities:** India has several development-related issues to deal with, such as expanding access to electricity and lowering air pollution. The implementation of CCS may be subordinated to these goals.
- **Alternative Solutions:** India is a dramatic alternative for cutting emissions because of its rapid expansion of renewable energy potential. Harnessing renewable energy may serve the a more practical and affordable option in some circumstances.

Therefore, it becomes necessary to understand the implications of using CCS technologies, but also in their implementation them in our country. The negative aspects of CCS discussed above does not rule out the possibility of using Carbon sequestration or Bioenergy Carbon Capture and Storage.

8. CONCLUSION

The paper offers an in-depth examination of the prospects of Carbon Capture and Storage (CCS) in India, with a particular emphasis on Coalbed Methane. It highlights the critical role of CCS in addressing climate change and setting down on carbon emissions, particularly in a sector marked by expanding industrial and energy sectors, such as India.

It's crucial to grasp the various elements, which encompass technological choices, appropriate geological sites for storage, and the integration of CCS within India's energy and industrial framework. The document examines the varied origins of emissions in Coalbed Methane and underlines the significance of custom, location-specific strategies for implementing CCS. Based on GHG-CO₂ emissions from year 2015 - 20, it shows that the major sectors of CO₂ emissions are the water distribution sector and buildings with an average range of 1500T CO₂ equivalent and 17500T CO₂ equivalent respectively in the Coalbed Methane district.

Over 14 lakh saplings planted in Coalbed Methane forest division in 9 years as part of efforts to improve green cover, officials of Coalbed Methane Forest Division planted 14.79 lakh saplings between 2013 and 2022, which supports the idea of carbon sequestration in silviculture.

Additionally, it's essential to recognize the vital role played by government policies and incentives in driving CCS initiatives, recognizing the well-structured regulatory frameworks and financial backing can expedite the adoption of CCS. The paper also stresses on the obstacles and constraints linked to CCS, including cost considerations, public approval, and the availability of resources.

From the *Potamogeton pectinatus* and *Sesuvium* species shows the maximum CO₂ Equivalents of about 341.71 kg of CO₂ and 493.33 kg of CO₂ in case of *Sesuvium* carbon capture and storage. In *Ip. Thunbergii*, a tall tree (*Tectona Grandis*) with a girth of 20-30 cm can absorb 1.20 lakh tonnes of carbon dioxide from the atmosphere.

In summary, it can be stressed that while CCS offers a hopeful avenue for India to curtail its carbon emissions, its full potential can only be realized through collaborative endeavours involving government agencies, industries, and stakeholders. As India aims to strike a balance between economic growth and environmental sustainability, CCS emerges as a valuable instrument in working toward net-zero emissions and confronting the worldwide issue of climate change.

REFERENCES

- [1] Oliver Funtke, Adrian Ranzani, Lili L. Weber: Carbon Capture and Storage in the United States: Perceptions, preferences, and lessons for policy. *Energy Policy*, 151(2021): 112149.
- [2] Tati Balakrishna, Harman, Mohan, and Deepak Yadav: Assessing India's Underground CO₂ Storage Potential: A Critical Analysis of What Lies Beyond the Theoretical Potential. *Cracked on Energy, Environment and Water (CEEW)*, 2023.
- [3] Hendrik Schwan, Oliver Riess: Carbon capture and storage: Lessons from a storage potential and location analysis. *Applied Energy* 188 (2017) 32–44.
- [4] Athena Adams, Patricia Thordley, Katie Cheng, Miryam Rader: Carbon dioxide removal potential from decentralised bioenergy with carbon capture and storage (BECCS) and the relevance of operational choices. *Resources and Bioenergy* 129 (2023) 106406.
- [5] Doretti Laro, Ryo Matsuyama, Akashi Kusunoki: A sustainable pathway of bioenergy with carbon capture and storage deployment. *Energy Procedia* 114 (2017) 4033–4035.
- [6] Ross M. Curran-Lucas, Adam Aspinall: Carbon capture, storage and utilisation technologies: A critical analysis and comparison of their life cycle environmental impacts. *Journal of CO₂ Utilization* 9 (2015) 82–102.
- [7] Yuting Liu, Wenshi Mooken, Huiyong Li, Liu Thoria, Xinyu Yao: Property impacts on Carbon Capture and Storage (CCS) processes: A review. *Energy Conversion and Management* 178 (2018) 204–222.
- [8] Andri Linnhardt, Kerstin Arndt, Julia Oeffmann-von Herck, Martin Zaefer: Uncovering attitudes towards carbon capture storage and utilisation technologies in Germany: Insights into affective-cognitive evaluations of benefits and risks. *Energy Research & Social Science* 48(2019): 230–238.
- [9] Sven Lohw, Stefan Schöber: Is bio-energy carbon capture and storage (BECCS) feasible? The covered authority of integrated assessment modeling. *Energy Research & Social Science*, 98(2020): 101526.
- [10] Michele Ferguson, Peter Ashworth: Message framing, environmental behaviour and support for carbon capture and storage in Australia. *Energy Research & Social Science*, 7(2021): 101901.
- [11] Meng Wang, Yunchao Gao, Meizi Wang, Yang Li, Yan Sun: Promoting support for carbon capture and storage with social matter: Evidence from a randomized controlled trial in China. *Energy Research & Social Science*, 34(2021): 101959.
- [12] Kevin Broocka, Gert-Jan, Emma ter Meer, Christina Brouwer, Sander Stadhoud: How do people perceive carbon capture and storage for industrial processes? Identifying factors underlying public opinion in the Netherlands and the United Kingdom. 01120211, 102234.
- [13] Arvind Kumar, Rakesh Ghoshal, Ravi Kumar, Varungh Kaurad, Ghansh Rishol: Significant aspects of carbon capture and storage – A review. *Petroleum*, 9(2019), 135–140.
- [14] Mohanish Padhede, Karan Nabil-Tank (Tactans goudh) *Parmanee awards Carbon Sequestration and Climate Change Mitigation in district Solapur*, *Mahya Prastak India*, Vol. 6, Issue 9, September 2017.
- [15] Shub Fahad, Arun Channarayana, Madhan Arun, Hishay Ullah Muhammad Saad, Imran Ali Khan Muhammad Adnan, *Environment, Climate, Plant and Vegetation Growth* Springer, 2023, ISBN: 978-3-030-40733-6, doi.org/10.1007/978-3-030-40733-6_725-1.
- [16] S. S. Rajesh, V. Divyashree, Saru P. B. Kamaladren, S. Manojkumar, A. Lakshminar, L. Paramasuri and M. Velmurugan: Carbon Sequestration Potential of C3i Palm Plantations in Tamil Nadu Region, India. *International Research Journal of Pure & Applied Chemistry*, 2020, DOI: 10.9734/IRJPAC/2020/52111100020.
- [17] S. V. Haroon, V. Divyashree, P. J. N. Maheshwari, J. C. Divyashree, D. P. Yee Varier and M. A. J. Bhadrachari: The climate change mitigation potential of bioenergy with carbon capture and storage. *Nature Climate Change*, 2020.
- [18] Yi-Ming Wu, De-Ning Kang, Lin-Cai Lin, Qi Li, Peng-Tao Wang, Jiao-Sun Zhu, Qian-Mei Liang, Hua-Tian, Shi-Feng Huang and Bi-Yang Yu: A proposed global budget of carbon capture and storage in line with a 1.5°C climate target. *Nature Climate Change*, 2020.
- [19] Paolo Gabrielli, Matteo Gervasi and Mauro Mancini: The Role of Carbon Capture and Utilization, Carbon Capture and Storage, and Biomass to Enable a Net-Zero-CO₂ European Chemical Industry. *Industrial and Engineering Chemistry Research*, 2020.
- [20] Christopher Conant: *Bioenergy and Carbon Capture and Storage*, Global CCS Institute, 2019 Perspective.
- [21] Chandan Sahu, Hemant Kumar Nayak, Sanjay Kumar Sahu: Carbon Sequestration potential of trees in an urban area: A case study of umbelipa tree in Kanker Talia, Tezpur, India. *Environmental Bulletin*, Volume 29 – No. 18(2000), 2755–2766.
- [22] Priyanka Choudhary, Nishita Sanki, Megharshi Vaidyanathan, Indu Ash: Assessment of the overall carbon storage in a rock plantation in Kanchanbhor.

- meritane, Thailand – Implications for carbon-based incentives. *Climate Environmental Systems*, 2(2021), 88822.
- [22] Kishu Sharma, Lohit Pradhan, Mary Kuttan and Prabhat Bhattacharya. Assessment of Carbon Sequestration Potential of Tree Species in Amity University Campus, Noida. *Environmental Science Proceedings*, 1(2021), 32.
- [23] A. Mary Saral, S. Mallyakale and Koorthana Devi. *ICP Conf. Series Materials Science and Engineering* 143 (2017) 022005. doi:10.1063/1.5014995/283-2-022005
- [24] Hans-Peter Schmid, Andrés Ariza-Correa, Nicolás Hagemann, Christian Weyant, Dieter Lamm, Wolfgang Lucht, Christa Kummer, Pyrolytic carbon capture and storage. *GCB Bioenergy*, 20(4)(2017), 373–380.
- [25] Lawrence Lohr. Global costs of carbon capture and storage. *Global CCI Institute*, 2017.
- [26] Muhammad Zubair, Ghulam Yasin, Rafique Khan, Qasim Ali, Ahsan U. Haq, Ahsan Ali, Muhammad Yaseen, Shafiq U. Rehman and Wei Guo. Carbon Sequestration by Native Tree Species around the Industrial Area of Southern Punjab, Pakistan. *Land* 2022, 11, 1877.
- [27] Wang, Yan, Fan, Zhao, Zhang. Wenhong. *Biomass*, Total 4, 11, Wu, Zheng, Zhao. Life cycle assessment of combustion-based electricity generation technologies integrated with carbon capture and storage: A review. *Environmental research*, 2021.
- [28] Mandeep Kaur, H. M. A. Mohsen, V. L. Duffield. Carbon storage and sequestration potential of selected tree species in India. *Ming Adact Energy Glob Change* (2018) 13:409–136.
- [29] A. Mary Saral, S. Mallyakale and Koorthana Devi. Carbon storage and sequestration by trees in VIT University campus. *ICP Conf. Series Materials Science and Engineering* 143 (2017) 022004.
- [30] National Action Plan on Climate Change (NAPCC), Ministry of Information and Broadcasting, Government of India, 2021.
- [31] Hottelch Kishor, May Kiser and Pabla Rensde. *CO₂ and Greenhouse Gas Emissions*, 2021.
- [32] Kefeng Wang, Gong Wang, Le Chang. *Research Progress in Carbon Dioxide Storage and Enhanced Oil Recovery*. *KIP Conference Series Earth and Environmental Science*, 2018, 113(1):1–104.
- [33] Zhongyue Lu, Paul A. Miller, Qiong Zhong, Benjamin Smith. Vegetation Pattern and Terrestrial Carbon Variations in Part Warm and Cold Climates. *Geophysical Research Letters* 46(14), 2019.
- [34] Rangaraj ChandraSekaran and Subramanyam. Estimation of biogas generation rate and carbon sequestration potential from two landfill sites in southern India. *Environmental Science and Pollution Research*, 29, pages(5011–5024) (2022).
- [35] Manoj Das, Anshu Srivastava, Arinashilam Rajagokumar, Bhishma Tyagi. Above ground carbon stock mapping over Coimbatore and Nilgiris Biosphere: a key source to the C sink. *Carbon Management* 13(2):1–15, 2021.
- [36] India's third biennial update report (BUR3), UNFCCC, 2021.
- [37] Global Carbon, 2019.
- [38] New India Express 2022, <https://www.newindiaexpress.com/Nation/India/article/2022/sep/28/over-18-lakh-trees-planted-in-coimbatore-forest-declare-as-a-park-2456261.html>
- [39] Rohit Dugg, Soumyajit Mukherjee. The development of carbon capture and storage (CCS) in India: A critical review. *Carbon Capture Science & Technology*, 2 (2022), 100036.
- [40] ClimateActionPlan Action Plan. *Coimbatore, ICLD-Local Governments for Sustainability*, 2018.
- [41] Jackie Vanhamel. *Preventing climate change with forest: reconciling with carbon capture and storage*, PhD-Princeton University, 2020.



Investigation of different origin fried oils and its biodiesel using Gas Chromatography – FID Chromatogram

Arunthra Vengasolai

Darun S S

Research Scholar

Postgraduate

Department of Chemical Engineering

Centre for Waste Management,

Sathyabama Institute of Science and Technology

Sathyabama Institute of Science and Technology

Chennai 600119

Chennai 600119

Email: arunthra2001@gmail.com

Email: darun@jssatishram.ac.in

Abstract

The primary motivation for exploring biofuels is to meet the world's energy needs. Demand for fossil fuels is increasing significantly due to population expansion. Biodiesel is a promising renewable energy source that, if implemented effectively, has the potential to reduce dependence on fossil fuels. Biodiesel production from waste cooking oil provides a three-pronged solution for economic, environmental, and waste management. In this work, local restaurant oil of popular brand was purchased from the market. Free fatty acid (FFA) of raw restaurant oil and fried oil samples obtained after single frying of different foods like potato, chicken 03, chicken nuggets, fish, banana legs, paneer vada, idli, idli dapp, fryan and papad were determined. Of the fried oils, the banana leg fried oil and chicken nuggets fried oil alone were chosen to be converted into biodiesel. The composition of the oil samples was determined using Gas Chromatography Flame Ionization Detector (GC-FID). Then the fried oils were converted into biodiesel by transesterification process and the composition of the product biodiesel was also determined using GC-FID. The chromatogram are useful to understand the presence of several hydrocarbons with varying fatty acid chains that influence the chemical and physical properties of the raw, used fried oils and the biodiesel derived from them. This data will be used as a base for using modeling platforms to obtain a process for production of biodiesel with desired product purity, limited alcohol requirement and reduced wash water requirement addressing Sustainable Development Goals 7 and 11.

Keywords: Waste Cooking Oil, Biodiesel, Gas Chromatography-FID, Free fatty acid, hydrocarbons.

INTRODUCTION

In the realm of renewable energy, exploring diverse fried oils as biodiesel sources holds great promise. These oils,

often discarded post-cooking, offer a sustainable alternative to fossil fuels [1]. Employing Gas Chromatography – Flame Ionization Detection (GC-FID) Chromatogram analysis, this study meticulously dissects these oil compositions. It unravels fatty acid profiles, hydrocarbon compositions, and molecular constituents from varied sources. Unveiling chemical properties like free fatty acid content and unsaturation levels becomes pivotal, impacting biodiesel stability and quality [2]. This in-depth investigation aims to reveal subtle nuances in oil compositions through precise analysis, unlocking insights crucial for biodiesel viability. Unraveling these molecular intricacies not only reveals biodiesel potential but also guides optimal conversion processes [3], fostering sustainable and eco-friendly biodiesel production [4]. Investigating biodiesel from diverse fried oils nurtures second-generation principles, advancing eco-friendly options by repurposing non-food sources. Analyzing these oil compositions via Gas Chromatography dissects molecular biodiesel behaviour, contributing to a greener fuel future. Concretely, biodiesel oil unlocks its untapped renewable energy targets [5], steering towards a cleaner, and more sustainable future [6]. Exploring diverse fried oils as biodiesel sources aligns seamlessly with biodiesel's broader significance, advocating sustainable energy solutions vital in combating climate change and ensuring environmental stewardship for future generations.

Excessive waste cooking oil disposal poses serious environmental and health risks [7]. It causes drainage clogs, leading to expensive repairs and sewage issues [8]. In water bodies, it disrupts ecosystems, suffocating marine life and disrupting oxygen exchange [9]. Soil contamination impacts fertility, hindering plant growth and the food chain. Reusing this oil in cooking risks harmful compounds, posing health threats like heart

household [10]. Improper management worsens the carbon footprint, emitting methane and increasing climate change [11]. Not recycling this resource into biodiesel wastes potential for reducing local fuel dependency and embracing circular economy practices [12]. Efforts to responsibly repurpose waste cooking oil into biodiesel are pivotal in curbing these dangers. Effective management mitigates pollution, fosters sustainable energy, and sets carbon emission for a more environmentally conscious future. Recycling waste cooking oil into biodiesel offers diverse environmental benefits, reducing water and soil pollution while mitigating harmful effects on aquatic ecosystems [13]. This process, aligned with circular economy principles, promotes resource conservation and domestic energy security, lessening dependence on volatile global oil markets. Converting waste into a valuable fuel source not only addresses environmental concerns but also fosters economic growth and cleaner air quality [14].

II. METHODOLOGY

A. Raw oil

Sunflower oil of a popular brand was purchased and used for frying different food materials including potato, chicken BS, chicken nuggets, fish, Banana bhaji, paneer vada, Indian Dahiya, Dahiya and Dahiya. All the items were fried one item in 200 ml oil taken separately for each food item. The frying temperatures and time ranged between 120°C – 140°C and 10 to 60 minutes. Analysis of the fried oil samples to examine changes in color, odor, and viscosity post-frying. A controlled frying process was executed to simulate real-world cooking scenarios using sunflower oil. The used-time fried oil was collected and stored in airtight containers to determine FFA.

B. FFA analysis

The free fatty acid (FFA) content of the collected different origin oils was tested as per ASTM D1601. 2 grams of waste cooking oil was taken in a clean, neutral flask and it was mixed with 0.15ml of isopropyl alcohol and heated to 60 °C. Then the mixture was cooled to room temperature and the sample was titrated with 0.1 N NaOH with an addition of two drops of phenolphthalein indicator till the change of color was witnessed. The final value is used in the determination of FFA according to the following equation 1.

$$FFA = \frac{\text{Mass of base reacting with acid}}{\text{Weight of the sample}} \quad (1)$$

The fried oils were analyzed for the FFA. If the FFA of the oil is less than 4%, a single step transesterification procedure is adopted. When FFA was greater than 4% a double step acid esterification followed by alkali

transesterification is adopted for biodiesel production. The FFA of all the oil samples determined are given in Table 1.

C. GC-FID TCD analysis

The Gas Chromatography was equipped with Flame ionization detector (FID). A TR-WAX (Thermo Scientific) capillary column of length 30 m, diameter 0.25 mm and thickness 1 µm packed with Polyethylene Glycol was used in the present study. Helium was used as a carrier gas at a constant flow rate of 1 ml/min. The optimum and maximum temperature for FID were set as 471 K and 313 K, respectively. The oil samples whose FFA was least and highest among all were chosen for the study. The Gas Chromatography analysis of fried oil samples and their respective biodiesel after transesterification was done for comparison. The chromatograms and the composition of both fried oil, chicken nuggets fried oil and their respective biodiesel samples are given in Fig.1, Fig.2 and, Tables 2 and 3. After the sample run was over, the oven temperature was cooled back to 313 K so that the subsequent run could be started.

D. Lab scale biodiesel production

Transesterification reactions were carried out in a 500 ml flat bottom glass reactor with a magnetic stirrer. The banana bhaji and Chicken nuggets fried oils were heated to 60°C to remove the moisture. First, a known quantity of sodium hydroxide (3% by weight of the oil taken) was dispersed in 4.5 ml of methanol/petroleum ether mixture [15] under magnetic stirring. The methoxide was then added to the preheated oil samples [16] and the reaction temperature was maintained at 60°C. The reaction was allowed to take place for one and a half hours. After the reaction time the two-phase product was formed as a result of transesterification reaction. Then the two layers were separated using a separating funnel. The upper layer consists of biodiesel, which is crude and needs refining. The lower layer consists of Glycerol, excess alcohol, catalyst, soap, and traces of unreacted oil. Refining of the biodiesel in the upper layer was done by washing with warm water (60°C). As the water was immiscible with biodiesel it can be easily separated from biodiesel using separating funnel. The washing was repeated with warm water until the washed water became neutral. Then the washed biodiesel was heated to 110°C to remove excess moisture. The sample was further analyzed for its composition using GC-FID.

III. RESULTS AND DISCUSSION

A. Free Fatty Acid Determination

The oil samples were subjected to FFA analysis and the results are shown in Table 1. It is observed that both the oil samples show lower FFA percentage. It may also be

whereas that the chicken suggests fried oil has more TFA than Banana Bajji fried oil.

Table 1: TFA of Fried oils

S.No	Oil	TFA
1	Banana Bajji fried oil	0.22 %
2	Chicken suggests fried oil	0.30 %
3	Panipuri fried oil	0.20 %
4	Panipuri fried oil	0.20 %
5	Ladyfinger fried oil	0.23 %
6	Appalam fried oil	0.33 %
7	Frypan fried oil	0.23 %
8	Fish fried oil	0.34 %
9	Chicken A5 fried oil	0.20 %

According to the results it was observed that both the oils have less than 4% TFA. Therefore transamination process was followed for the bio diesel production.

B. GC-FID HCD Determination:

The results of GC-FID of both Banana bajji and Chicken suggests fried oils were given in the table 2 and 3 and figures 1 and 2.

Table 2: GC-FID results of Banana Bajji fried oil

Reten. Time [min]	Area [mV.s]	Height [mV]	Compound Name	Concentration %
3.147	3.563	0.298	C8:0	0.0047039
3.75	1.311	0.298	C8:0	0.0020079
6.89	12.577	1.394	C10:0	0.0238043
8.177	89.746	7.365	C14:0	0.1678302
12.147	7.331	0.313	C18:2	0.0134089
13.4	12.508	0.717	C20:0	0.0229122
14.37	15.988	0.566	C21:0	0.0292457
16.563	6.857	0.51	C22:3n6	0.0118286
18.857	49.637	3.857	C17:0	0.0738990
19.373	127.226	8.894	C17:0	0.2527957
20.65	82.397	10.23	C17:0	0.1689277
20.88	280.823	26.152	C17:0	0.5673280
21.877	138.72	7.262	C17:0	0.2803088
27.29	1511.923	130.278	C18:1	27.6081346
28.973	1066.488	154.568	C18:3n6	18.7843110
30.777	28795.026	132.732	C18:3n6	52.6681278



Fig.1 : GC-FID results of Banana Bajji fried oil

Table 3: GC-FID results of Chicken suggests fried oil

Reten. Time [min]	Area [mV.s]	Height [mV]	Compound Name	Concentration %
3.247	4.515	0.298	C8:0	0.0074398
3.753	4.441	0.298	C8:0	0.0073883
6.473	1.424	0.298	C8:0	0.0020723
6.59	0.121	0.298	C8:0	0.0133642
6.76	17.524	1.672	C10:0	0.0288181
7.483	11.116	0.894	C13:0	0.0182928
8.054	756.328	68.888	C14:0	1.2448774
8.897	3.454	0.303	C17:0	0.0089753
10.67	3.8	0.313	C17:1	0.0082334
11.673	5.262	14.239	C18:2	0.0088823
12.47	4.354	0.433	C18:2	0.0070008
12.783	8.419	0.343	C18:3n6	0.0118548
12.85	2.384	0.36	C18:3n6	0.0039232
14.33	12.813	0.483	C21:0	0.0238888
14.267	1.298	0.186	C21:0	0.0021127
16.433	1.302	1.375	C22:3n6	0.0018862
17.567	22.18	67.613	C24:1	0.0405882
18.367	31.983	76.973	C17:0	0.0726488
18.877	15.184	1.768	C17:0	0.0248813
19.38	49.949	4.819	C17:0	0.0821976
20.133	51.653	4.654	C17:0	0.0404813
20.9	196.727	15.315	C17:0	0.3118673
21.88	186.2	5.038	C17:0	0.326163
24.887	2641.762	45.688	C18:0	5.9030362
27.443	10648.786	112.888	C18:1	26.4188888
30.073	7836.307	109.313	C18:3n6	12.6023453
30.913	29666.642	100.888	C18:3n6	48.8281888

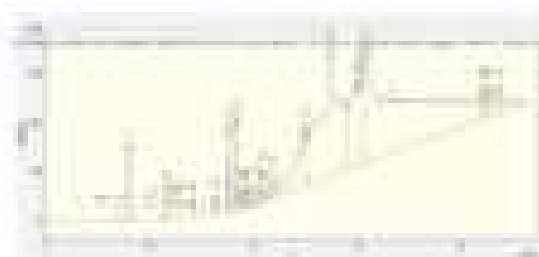


Fig.2 GC-FID results of Chicken nuggets fried oil
The results of GC-FID of both banana leaf and chicken nuggets fried oils derived biodiesels are given in the table 4 and 5 and Fig. 3 and 4.

Table 4: GC-FID results of Banana leaf fried oil derived Biodiesel

Reten. Time [min]	Area [mV.s]	Height [mV]	Compound Name	Concentration %
8.18	21.43	1.48	C14:0	0.0075728
10.22	8.57	0.52	C17:0	0.0031479
11.33	39.34	1.16	C18:2	0.0144534
15.43	472.74	15.47	C22:0	0.1736876
16.72	25.01	1.48	C22:3n6	0.0084529
17.28	33.39	2.37	C24:0	0.0136162
18.22	137.43	14.62	C17:0	0.0536612
19.77	437.39	25.28	C17:0	0.1607016
21.79	403.89	41.17	C17:0	0.1475339
22.11	14894.72	879.63	C17:0	5.4734219
23.76	764234.68	4772.64	C17:0	79.7727738
26.42	9461.19	221.75	C18:1	3.5282648
26.43	13297.36	388.79	C18:2	4.8836136
30.19	6463.73	39.37	C18:3n6	2.1735686
33.08	19888.32	46.54	C20:0	7.3875472



Fig.3 GC-FID results of Banana leaf fried oil derived Biodiesel

Table 5: GC-FID results of Chicken nuggets fried oil derived Biodiesel

Reten. Time [min]	Area [mV.s]	Height [mV]	Compound Name	Concentration %
5.33	1.43	0.30	C8:0	0.0003875
11.33	4.33	0.59	C8:0	0.0009642
15.77	15.72	0.45	C12:0	0.0026299
18.13	38.36	1.87	C14:0	0.0135957
19.47	412.89	39.18	C14:0	0.5407674
19.77	3.56	0.33	C20:0	0.0072833
19.14	715.77	54.39	C22:0	1.0103822
19.55	26.39	0.47	C22:3n6	0.0036121
17.08	7.36	0.72	C24:0	0.0088148
18.18	2811.34	138.78	C17:0	1.6791383
19.97	66.48	6.63	C17:0	0.0073647
20.82	396.91	13.48	C17:0	0.0071256
22.08	2669.66	222.49	C17:0	1.6883472
23.69	56941.87	1293.62	C17:0	11.0136741
25.00	1336.89	48.94	C18:1	2.0134385
26.76	6329.77	104.74	C18:2	8.3059679
27.64	3874.89	61.39	C18:3	4.0334046
28.76	8147.81	38.03	C18:2	10.6928894
30.37	7327.21	52.81	C18:3n6	9.6151282
33.08	17407.78	25.67	C20:0	21.8433345



Fig.4 GC-FID results of Chicken nuggets fried oil derived Biodiesel

Gas Chromatography – Mass Spectrometry Detection (GC-MS) analysis offered detailed insights into the molecular composition of the biodiesel samples. Fatty acid methyl esters (FAMEs) exhibited diverse profiles, reflecting the diverse origins and frying conditions. Fatty acid saturation ratios varied, suggesting inherent compositional differences in triglycerides and fatty acids, vital for understanding their performance as biodiesel feed stocks.

IV. Conclusion

The comprehensive investigation into diverse origin feed oils as potential biodiesel sources, coupled with meticulous analyses and assessments, sheds light on critical aspects of sustainable fuel production. The investigation of characteristics, ASTM-standard evaluations, and GC-MS analysis unveiled intricate relationships between frying conditions, raw oil properties, and the resulting biodiesel characteristics.

REFERENCES

- [1] Singh, A. P., and Deep Singh, "Biodiesel production through the use of different sources and characterization of oils and their esters as the substitutes of diesel a review," *Renewable and sustainable energy review* 14.7 (2010): 208-214.
- [2] Singh, Deepinder, et al. "Chemical compositions, properties, and standards for different generation Biodiesels: A review," *Fuel* 257 (2019): 106-71.
- [3] Patra, Pradyota, et al. "Recent advances in systems and synthetic biology approaches for developing novel cell-factories to non-conventional feeds," *Biochemistry Advances* 67 (2021): 107987.
- [4] Gadhwal, Apoorva, et al. "Sustainable biodiesel production from agricultural residues: an eco-friendly approach: a review," *International Journal of Environment and Climate Change* 13.10 (2023): 2005-2014.
- [5] Saravanan, Aradhana Perumal, Arunaganesan Pappaswathi, and Thirugavil Mathivanan. "A comprehensive assessment of biodiesel policies in the OECD nations: Explorations, findings, gaps and gaps," *Fuel* 272 (2020): 117633.
- [6] Miralili, Husein, İhsan Dilek, and İrfan İsmail Kırıcı. "Cleaner technologies for sustainable development," *Chemical Engineering and Technology* 7 (2022): 100445.
- [7] Gadhwal, Jyoti, and Sayed Mahmood Karim Uddin. "Household waste and health risks affecting waste pickers and the environment in low-and middle-income countries," *International Journal of Occupational and Environmental Health* 23.4 (2017): 298-310.
- [8] Wallace, Thomas, et al. "International practice of 3d, 4d and green (GEO) waste management: A review," *Journal of environmental management* 187 (2017): 424-435.
- [9] Thakur, Arshita, and Bhagendra Kaul. "Impact of oil explosion and spillage on marine environment," *Advances in Oil-Field Separation Chem.* 2022, 113-115.
- [10] Ganesan, Ramar, Kanniah Subalingam, and Rajesh Kumar. "Impact of consumption of supposedly heated/cooking oils on the health of various animals: A critical review," *Critical reviews in food science and nutrition* 59.3 (2019): 408-447.
- [11] Othman, Mona E., et al. "Environmental assessment of three different utilization paths of waste cooking oil from households," *Resources, Conservation and Recycling* 106 (2016): 23-47.
- [12] Sharma, Pankaj. "Optimized conversion of waste vegetable oil to biodiesel with Meta heuristic methods and design of experiments," *Journal of Emerging Areas and Engineering* 1.1 (2022): 22-28.
- [13] Kumar, Yitao, et al. "Microbial nanoplanting (MNP) as emerging pollutant in ground water: Environmental impact, potential risks, limitations and way forward towards sustainable management," *Chemical Engineering Journal* 439 (2022): 144-568.
- [14] Hamed, Hamed. "Impact of economic growth, nonrenewable and renewable energy consumption, and urbanization on carbon emissions in Sub-Saharan Africa," *Environmental Science and Pollution Research* 25.15 (2018): 15057-15067.
- [15] Ali, Rezaul, S.S. Datta, J. Jayaraman, N. Haniffa, K. Vekari, S. Ali Salim. "Experimental investigation on effect of MgO nanoparticles on cold flow properties, performance, emissions and combustion characteristics of waste cooking oil biodiesel," *Fuel*, Volume 230, 2018, Pages 768-781.
- [16] Sathishk, A., and S. S. Datta. "Synthesis of zinc chloride activated cross-linked nano-adsorbent (activated carbon) from coal waste for removal of pollutants from biodiesel/water," *Water Science and Technology* 81.5 (2021): 1178-1181.

Baker Hughes

- Baker Hughes is a leading energy technology company that provides solutions for energy and industrial customers worldwide
- We design, manufacture, and service transformative technologies to help take energy forward – making it safer, cleaner, and more efficient for the people and the planet
- This is made possible through our technology, our people, our scope and scale, and our low-carbon commitment
- We harness the power of engineering, data, and science to redefine what is possible
- Baker Hughes has integrated offerings and a unique set of products and services across two business segments: Oilfield Services & Equipment (OFSE), and Industrial & Energy Technology (IET)
- We are an energy technology company with a diverse portfolio of equipment and service capabilities that span the energy and industrial value chain. Our two operating segments are organized based on the nature of our markets and customers and consist of comparable products and services
- Powered by the industry's only end-to-end solutions technology portfolio, and enabled by our people and scale, we drive productivity and improve outcomes for ourselves and our customers
- From the first rotary drill bit to the world's most extensive portfolio of compressors and gas turbines, and from digital solutions that predict outcomes to modular deep water technology, for more than a century our inventions have been revolutionizing the energy industry
- Conducting business in over 120 countries and with approximately 55,000 employees, we design, manufacture and deliver leading technology solutions for our customers
- We are reducing the carbon intensity of our operations, applying proven low-carbon technology to help our customers meet their environmental goals, and innovating for the future of energy

Our global footprint: some quick facts

- In 2022, our global revenue was \$24.2B (USD). For more information on our financials, see the section on financial performance
- We are headquartered in Houston, Texas, USA and London, UK
- We are listed on the NASDAQ Stock Exchange as NASDAQ: BKH
- We are global, but we are local too. Conducting business in 120+ countries worldwide with ~55,000 employees

Identification of Optimum Location and Designing of Sustainable Charging stations for the electric vehicles – A case study of Coimbatore and LPA

Thilagott A¹, Babu V², Siddharth Krishna³, Vamsath Ragul⁴, Ragul Adithya⁵, Rakshit⁶, Dhanush Raghan⁷, Dhanash⁸

¹Associate Professor, Department of Civil Engineering, PSG College of Technology, Coimbatore

²Associate Professor, Department of Mechanical Engineering, PSG College of Technology, Coimbatore

³UoI-Student, PSG College of Technology, Coimbatore

⁴Corresponding authors: ajp.civil@psgtech.ac.in, rdhanush@gmail.com

Abstract – The transition to electric mobility is a promising global strategy for decarbonizing the transport sector. India is among a handful of countries that target to have at least 30% of new vehicle sales be electric by 2030. An accessible and robust network of electric vehicle charging infrastructure is an essential prerequisite to achieving this ambitious transition. A case study on Coimbatore and Local Plan Area is taken into consideration to enable faster adoption of electric vehicles and promote sustainable development. The possibility of providing renewable energy sources for stations has been explored. The optimum location and number of charging stations found in this project can be implemented in real-time to establish charging stations in Coimbatore city and the Local Planning Area. The concept of green building has been evaluated as per the LEED rating system. The methodology adopted in this study to locate charging stations can be used in different study areas as well. This study enables the Coimbatore city to build its Electric Vehicle Infrastructure efficiently and sustainably.

Index Terms – Charging station, Coimbatore Local Planning Area, Electric mobility, Green rating, Optimum location.

1. INTRODUCTION

The 'Faster Adoption and Manufacturing of Electric and Hybrid Vehicles in India' (FAME) scheme is administered by the heavy industry department since April 2013 and it aims to bolster the adoption of Electric vehicles (EVs) in India. The provision of charging station infrastructure is the basic necessity to achieve this goal. The major limitation in mass shift to electric vehicles is "Range Anxiety" and that is why consumers are hesitant to purchase electric vehicles. FAME India is a part of the national electric mobility mission plan. The main thrust of FAME is to encourage electric vehicles by providing subsidies. The scheme proposes for the establishment of charging infrastructure, whereby about 2500 charging stations will be established in metros, smart cities, and cities of tally states across the

country so that there will be the availability of at least one charging station in a grid of 7 Km x 7 Km.

Aim

This paper aims to develop a comprehensive charging infrastructure that will facilitate the widespread adoption of electric vehicles, in line with the national electric mobility mission plan.

Objectives

- To develop a comprehensive charging infrastructure that will facilitate the widespread adoption of electric vehicles, in line with the national electric mobility mission plan.
- To explore the possibilities of renewable energy sources for charging stations.
- To plan and design a typical electric charging station on a highway.
- To estimate the cost of the proposed typical charging station.

For FAME Scheme

- Encourage faster adoption of electric and hybrid vehicles by way of providing an upfront purchase incentive for electric vehicles.
- Establish a necessary charging infrastructure for electric vehicles.

Yashwanth Kandamuri [1] developed a dynamic GIS model for optimum location identification of plug-in electric vehicle charging stations. Balraj Coudra and Coudra Coudra [2] have determined the charging infrastructure location for electric vehicles and have elaborated a weighted multicriteria method for both the national goals and domains.

II. METHODOLOGY

A. Study Area

The Coimbatore City and Coimbatore Local Planning Area (LPA), a city in Tamil Nadu is the study area considered for this study. The city is situated on the banks of the river Noyyal, in the semi arid region of the Western Ghats. Coimbatore enjoys a very pleasant climate all year round, aided by the fresh breeze that flows through the 25 km long Palakkad gap. The city has four special economic zones (SEZ), namely, Thuvaiyur, Chidambaram, Spinn Ventures and, Appan

Hris A. Thilagan, Rishi S. Subhathi Krishna, Yuvath Rajul, Rajul Adithya, Rakshit, Dhruvth Rajan and Dharmu

and at least five more cars are in the pipeline. Coimbatore has trade associations like COHIMA, COHIBA, and COHWEI, representing industries in the city. There are more than 25,000 small, medium and large-scale industries. According to the 2011 census, Coimbatore's population was 24,83,343, with a projected population of 18,26,000 by 2030. The total number of vehicles in Coimbatore is reported to reach 12,82,113 by 2030, with 92 % of them falling into the two-wheeler segment. Thus, the provision of infrastructure for electric vehicle charging is critical. This project aims to provide the optimum location and number of charging stations for Coimbatore LPA which is sufficient to meet the needs of mobility in the future.

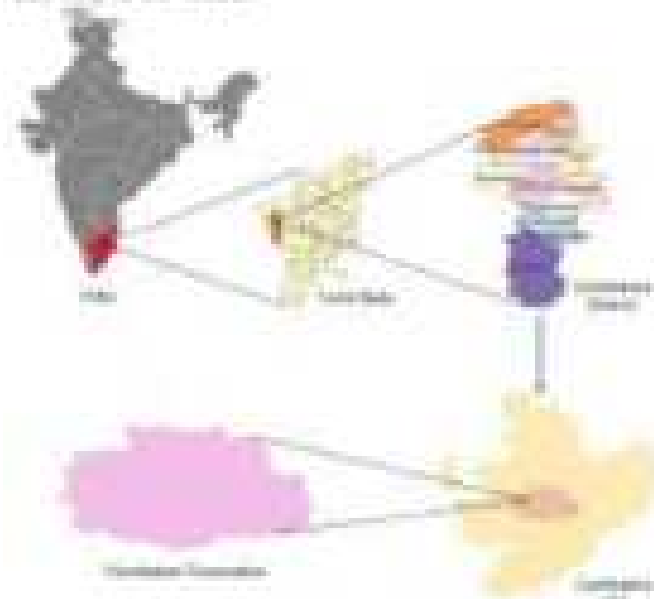


Figure 1: Location map of the study area

B. Digitization and creation of map layers

Quantum Geographic Information System (QGIS) is an open-source Geographic Information System program that is used to capture, store, and manipulate various forms of geographical data and it also aids in the creation of graphical maps and their report.



Figure 2: Digitized Coimbatore city map with map layer control.



Figure 3: Digitized Coimbatore LPA boundary with the road network.

The Coimbatore Corporation has four zones- North, East, West, and South which are further divided into multiple wards. First, each of the zone layers is created over one another and then digitized. Secondly, these zones are digitized one Ward.

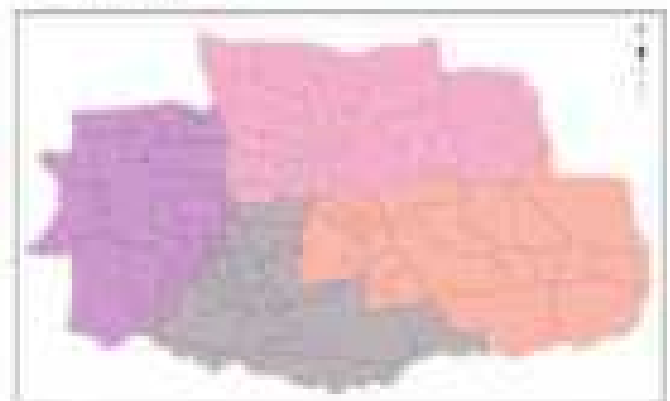


Figure 4: Coimbatore city mapping



Figure 5: City ward-wise population density map.

Identification of optimum location and designing of sustainable charging stations for the electric vehicles : a case study of Coimbatore and LPA.

All of the aforementioned information about the existing petrol bunk is entered into the Petrol Bunk Layer's fields for the whole LPA region of Coimbatore. There are a total of 232 petrol bunks in Coimbatore LPA, out of which 99 petrol bunks are located in Coimbatore Corporation limit.

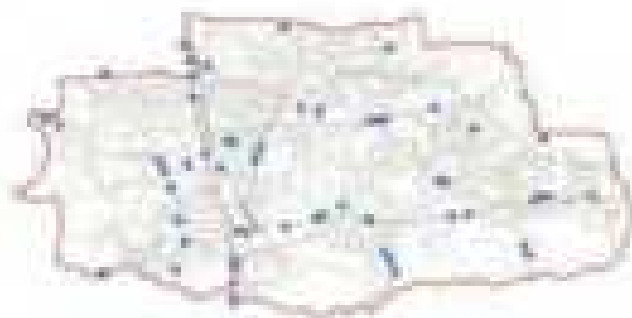


Figure 4: Existing petrol bunks in the city corporation limit

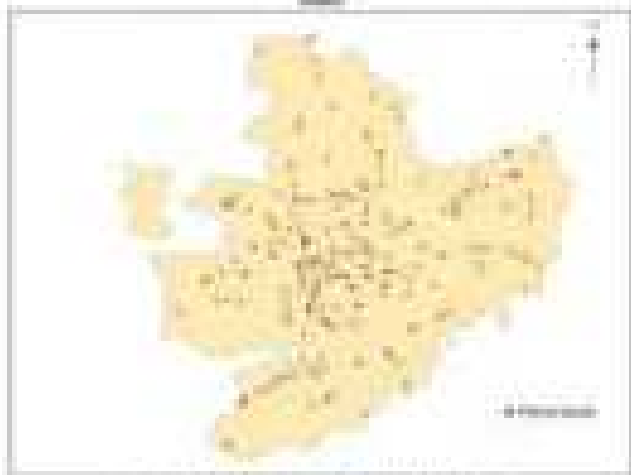


Figure 5: Existing petrol bunks in LPA Area

C. Optimum location of EV charging stations

The optimum location of charging stations is found [3] based on the following three criteria : Points of Interest, Grid of 3 km x 3 km, and Location of existing Petrol bunks.

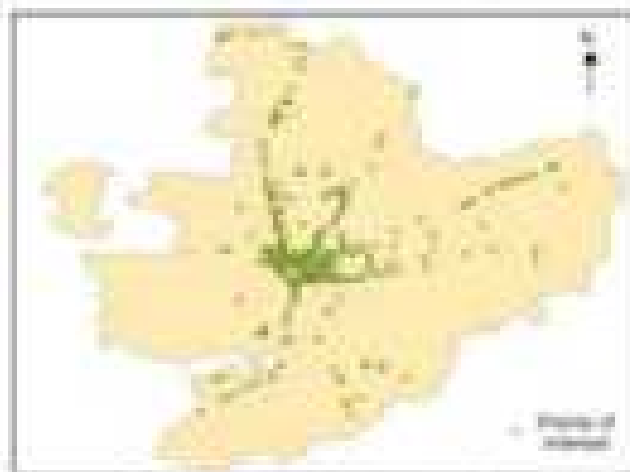


Figure 6: Map of Coimbatore - points of interest

The points of interest were located based on the following factors: population density, parking availability, traffic volume, commercial establishments, transit routes, and tourist places. These points of interest are converted into a heat map.

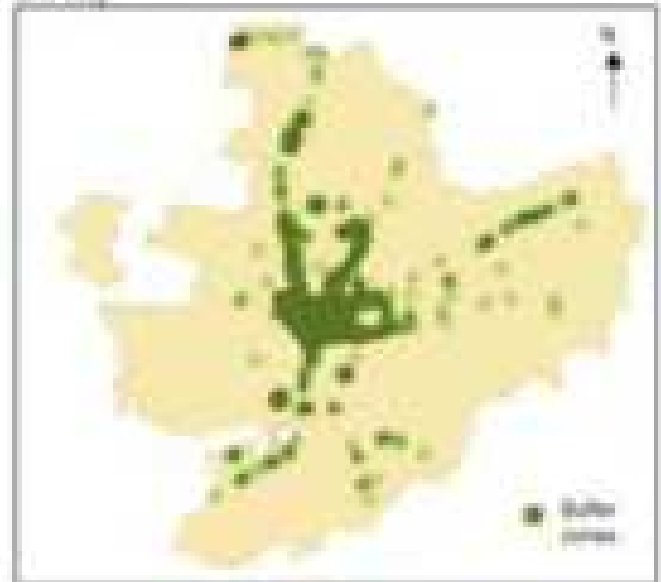


Figure 7: Heat map based on points of interest

According to the I AME II scheme, there should be at least one charging station in a grid of 3 km x 3 km in meters, other metropolitan cities, smart cities, and cities of Hilly states.

The heat map, existing petrol bunks, and grid are overlaid on each other. The heat map highlights important areas where charging stations should be located, with at least one charging station in each grid cell. As a result, new charging stations are proposed in significant areas based on the heat map, where there are no existing petrol bunks or where a grid has no existing petrol bunk in it.

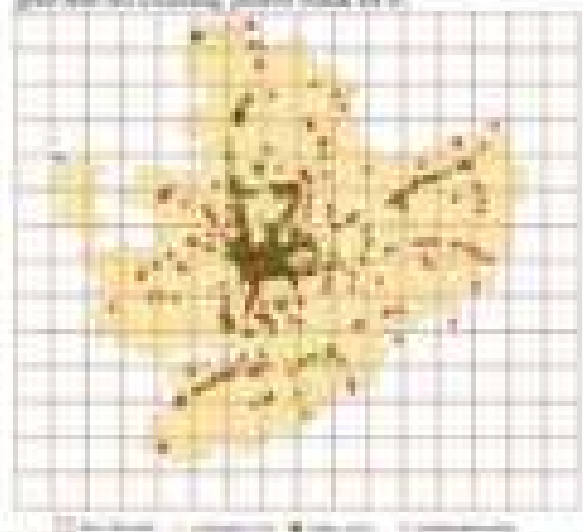


Figure 8: Heat map showing the existing petrol bunks with a 3 km x 3 km grid over Coimbatore LPA.

Mrs. A. Thirugan, Bala S. Subbarath Reddy, Vaseeth Rajul, Rajul Adithya, Rakshit, Chinnathi Rajagan and Dharmar

The Coimbatore LPN's land use map has been added as a layer. The identified areas where charging stations need to be proposed are then checked on Google Earth to confirm if the land is designated for commercial purposes as per the Coimbatore City 2022 master plan.

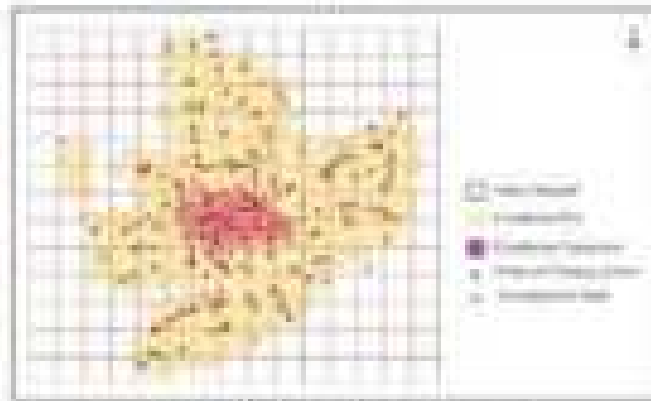


Figure 16: Proposed charging station

The Minimum and Maximum distance between two charging stations in grids are maintained at 5.000 kilometers and 3.5 kilometers respectively. This procedure is carried out for all grid cells that cover the entire Coimbatore Local Planning Area.

B. Analyzing future demand for charging stations in Coimbatore when the metro begins service.

In 2010, India's central government planned its metro rail system for 2 tier cities, including Coimbatore. In 2017, the railway ministry stated that the Central Government is prepared to develop and fund a metro rail project in Coimbatore and the Tamil Nadu government approved a plan for a metro rail in Coimbatore which has been approved by the state government. In 2021, the Tamil Nadu government set aside Rs. 6,000 crore to start the Coimbatore Metro Rail Project. In 2022, Finance Minister PTB.



Figure 17: Proposed metro rail corridor in Coimbatore (PTB)

Finance Minister announced the preparation of a detailed project report by CMRL, which is currently in the

final stages, central government money will be given soon, and construction will begin at the earliest.



Figure 18: Proposed metro rail corridor in Coimbatore



Figure 19: Charging stations in the proposed metro rail corridor

It has been confirmed that charging stations are located along metro rail route. There are 17 charge places along the proposed metro rail line, including 09 along the Aravankudi and Pollachi road, 10 along Nilakshi road, 17 along Subramanyam road, 14 along Trichy Road (Karasampettai to Ulakulam) and 8 along Narayan road (Karasampettai to Ulakulam).

E. Estimation of EV Charging Demand

An EV charging demand assessment can find how different aspects of charging infrastructure planning. It can be used as input data to set targets for the number of public EV chargers. It can also be used for location planning for public charging infrastructure and to analyze electric grid capacity and the need for reinforcements. EV charging demand is an output of regional level depends on per capita vehicle ownership rates, EV penetration levels, and vehicle utilization patterns [4]. First, the vehicles are divided into five segments – 2 Wheelers, passenger and cargo 3 Wheelers, and personal and commercial 4-wheelers.

Identification of optimum location and designing of sustainable charging system for the electric vehicles – a case study of Coimbatore and LPA

Table 1. Cumulative LPA vehicle population

Year	LPA	LPA	LPA Personal	LPA Commercial	Total
2020	140000	22000	20000	0000	162000
2021	140000	23000	20000	0000	163000
2024	140000	23000	20000	0000	163000
2025	140000	23000	20000	0000	163000

Table 2. Projection of vehicle population in 2025

Year	Annual growth			
	LPA	LPA	LPA Personal	LPA Commercial
2021	140000	22000	20000	0000
2022	140000	22000	20000	0000
2023	140000	22000	20000	0000
2024	140000	22000	20000	0000
2025	140000	22000	20000	0000
2026	140000	22000	20000	0000
2027	140000	22000	20000	0000
2028	140000	22000	20000	0000
2029	140000	22000	20000	0000
2030	140000	22000	20000	0000

Table 3. Cumulative vehicle population in Coimbatore LPA

Year	LPA	LPA	LPA Personal	LPA Commercial	Total
2021	140000	22000	20000	0000	162000
2025	140000	22000	20000	0000	162000

Table 4. Total vehicle population in 2025

Vehicle segment	LPA	LPA	LPA Personal	LPA Commercial
Personal	140000	22000	20000	0000
Commercial	140000	22000	20000	0000

Table 5. Total number of EVs in Coimbatore LPA in 2025

S. No.	Vehicle segment	Annual growth rate	EV proportion rate 2025	Total number of EVs in 2025
1	LPA	0.00%	0%	140000
2	LPA	0.00%	0%	0000
3	LPA Personal	0.00%	0%	0000
4	LPA Commercial	0.00%	0%	0000

Figure 17 shows the number of vehicles in each segment and their respective total charging demand in kilowatt-hours. This signifies that the Electric two-wheeler segment forms 90.14% of total electric vehicles in 2025 and takes up 94.7% of total charging demand in 2025 in Coimbatore LPA.

Table 6. Total daily charging demand in Coimbatore LPA in 2025

S. No.	Vehicle segment	Batteries per vehicle	Charging range per full charge (km)	Batteries capacity (kWh)	Batteries charging demand (kWh)	Total daily charging demand in 2025 (kWh)
1	LPA	40	100	1.2	1.2	140000
2	LPA	100	100	7	7	00000
3	LPA Personal	40	110	10.0	4	0000
4	LPA Commercial	100	100	10.0	10	0000

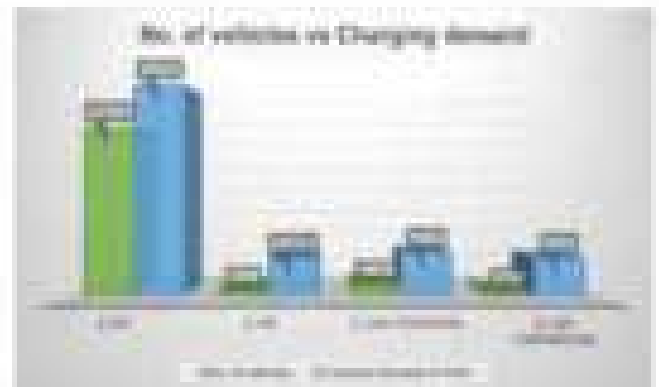


Figure 17. Number of vehicles vs charging demand

F. Exploring Solar power as a Sustainable Energy Source
Solar panels are a better sustainable energy source than the petrol-based energy can be converted into a solar panel system. The rooftop space for the existing fuel tank is measured individually. To locate petrol tanks and measure the rooftop area, Google Maps and Google Earth [1] are utilized, with the latter being used as a layer to GPRS software.

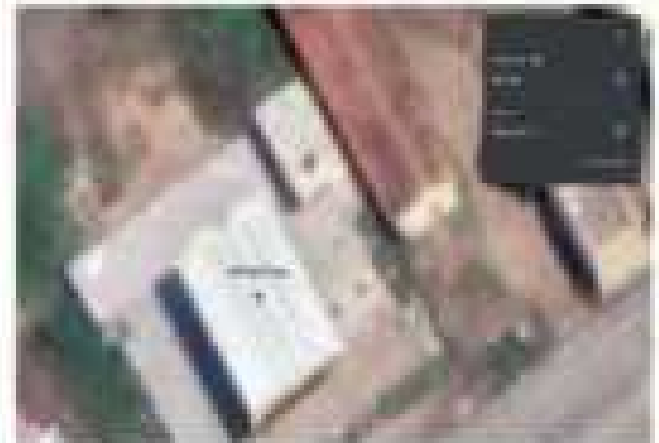


Figure 18. Locating vehicles in Google Earth

Table 7. Fuel used in Coimbatore LPA

S. No.	Segment Name	Total Amount
1	Personal Vehicles	10000
2	Commercial	10000
3	Personal Vehicles	10000
4	Commercial	10000
5	Personal	10000
6	Commercial	10000

Assuming that solar panels will cover at least 77% of the roof area i.e., 11262 m². Total energy supply from solar panels is 1,56,681 kWh. This covers 24.41 % of the total charging demand of electric vehicles in 2025 in Coimbatore LPA.

Mrs. A. Thilagam, Babu S. Subbarath Kandam, Viswanath Rajul, Rajul Adithya, Kallath, Dharmesh Rajhans and Dharmesh

G. Architectural Planning Aspects of Typical Charging Station

A typical charging station has a layout and design that can be replicated in every charging station. The typical charging station that will be designed is along a highway.



Figure 17: Proposed plan of the typical charging station.

The proposed charging station includes facilities (6) such as an ATM, a gymnasium, toilets, and a children's park.

Table 6: Area details.

S. No	Description	sq.ft	sq.m
1	Cafe & Office building	24000	2232
2	Toilet	100	9.30
3	Children Park	400	371.6
4	Waiting for charging	1000	93.04

The comprehensive 3D model of the typical charging station is developed using Blender (7).



Figure 18: Isometric view of the proposed charging station.



Figure 19: 3D front view of the proposed charging station.

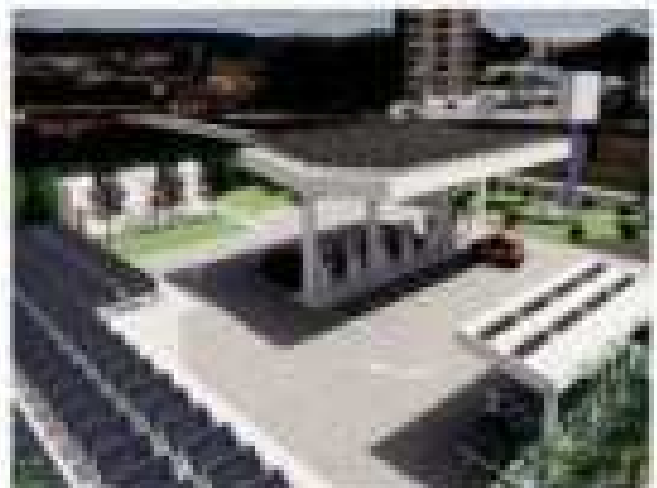


Figure 20: 3D comprehensive isometric model of the proposed charging station with area detail.



Figure 21: 3D comprehensive front view of the charging station.

Identification of optimum location and designing of sustainable charging station for the electric vehicles – a case study of Coimbatore and LPA



Figure 22: Aerial View of the Charging Station

Table 26: Location of solar panels in the proposed station

Location of panel	Number of 100 sq.ft panels
Front parking canopy	76
Open field in office building	76
Front Compound parking area	0
Total	152

The total energy output from the station is 164.4 kWh having 26 kWh as the output from the single 100-watt panel in a single day. Considering the maximum battery capacity of the car model as 24.2 kWh, the total number of E-cars that can be fully charged in the proposed charging station in a day is 17 EVs.

Cost Estimation

C. Cost of proposed charging station

As the proposed structural plan may vary in years depending on personal demands, in this study detailed estimation is questionable; therefore, one of the approximate estimation methods – the plumb line method is made used by taking into account the actual cost in Coimbatore.

Table 26: Details of approximate estimation of the proposed charging station

S. No.	Description	Cost (Rs.)
1	Construction of 100-watt solar heating including solar charge, inverter, aluminum frame & wire supply for around 2,400 sq.ft	30,00,000
2	Construction of land including solar charges, water supply for size of 400 sq.ft	14,00,000
3	Laying of 100-watt thick using 40 mm thick steel on both sides for around 2,400 sq.ft	1,77,194
4	Laying of 100-watt thick using 40 mm thick steel on both sides for around 2,400 sq.ft	17,76,200
5	Installation of ground for high road and canopy over vehicle charging area of size 1000 sq.ft	10,00,000
6	Laying of 100-watt ground for glass area of size 400 sq.ft	25,000
7	Installation of 100-watt solar charging station	1,75,00,000
8	Installation of 100-watt solar panels of size 10 x 7 sq.ft each	21,26,000
9	Total	1,00,09,194

The estimated approximate cost for constructing the proposed typical charging station is Rs. 1,00,09,194 (Ten crore Twenty-one Lakh Nine Thousand One Hundred and Fifty-one including land cost).

D. Cost comparison between solar power and electric grid supply

To obtain the percentage of charging cost that can be saved while adopting the solar power method, a comparison table is prepared.

Table 27: Charging cost comparison

S. No.	Description	Solar 4-watt/100		Grid 3-watt/100	
		Cost (Rs.)	Hours	Cost (Rs.)	Hours
1	Cost charged per car	0	1	0	1
2	Cost charged for 100 charging cars	100	211.2	211.2	111.6

Case (c) Business Model

The goal of a green building design is to:

- Reduce non-renewable resource demand,
- Increase the efficiency of those resources which are used,
- Optimize the reuse, recycling, and reuse of nonrenewable resources.

Green building rating of proposed typical charging station Leadership in Energy and Environmental Design (LEED) (®) is a innovation-based building grading system based on the usage of various building technologies. As in accordance with the LEED rating system, the proposed charging station has been evaluated.

LEED categories and credits

- Location and transportation – 16 credits
- Sustainable sites – 10 credits
- Water efficiency – 11 credits
- Energy and atmosphere – 15 credits
- Materials and resources – 13 credits
- Indoor environmental quality – 16 credits
- Integrative process – 01 credits
- Innovation – 06 credits

Regional priority – 0 credits

Table 28: Rating categories in LEED

Category	Points	LEED	Rating	Weighted
Total	61	60-74	50-60	50-60

Table 29: Green building rating for the typical charging station

Category	Points	Total Credits	Points
Integration	01/1	Integration process	01/1
Location and Transportation	11/16	Location and Transportation	11/16

Identification of optimum location and developing of sustainable charging station for the electric vehicles – a case study of Coimbatore and LPA

The analysis and facilities of a charging station and their locations are thoroughly addressed before beginning to design a 2D plan for the charging station. Apart from office space and charging area, a typical charging station includes [7] a restaurant/cafe, restroom, ATM, and lounge. Figure 13 shows a bubble diagram that consists of roughly drawn facilities (representing spaces) connected by solid lines, indicating lines, entry lines, etc. to specify the type of relationship between the spaces. The bubble diagram's main aim is to assist in comprehending the program and a strategy. Plotting of the charging station is performed using AutoCAD as shown in Figure 14, to arrange the various components systematically to form a meaningful and homogeneous structure in next to dimensional program [8]. The area details are mentioned in Table VIII.

12. Discussion on the approximate estimation of the proposed charging station and cost comparison

An approximate estimation is a rough cost estimation prepared to obtain an approximate cost in a short time. As the proposed structural plan may vary in time depending on personal demands, detailed estimation is spontaneous; therefore, an approximate estimation method – the Plinth area method [9] is adopted for the estimation which is prepared on the basis of the plinth area of the building which is the area covered by external dimensions of building at the floor level. The plinth area of building is the cost of a similar building with specifications in that locality. The solution came we obtained from actual requests and contractors in Coimbatore viz., Akshaya projects, Coimbatore, The Engineers, Coimbatore, Infiniti structure Private Ltd, Vidharat Sagar Ltd.

The calculation for finding the cost of electric power from solar panels per unit

Cost of solar units obtained per day = (total cost of installing solar panel) / (No. span of solar panels in days)
 $= 17,26,000 / 925$
 $= Rs. 1864$

Cost of 1 unit of power from solar panel = $364 / 1864$
 $= Rs. 1.97 = maintenance cost$

Maintenance cost of solar panel per day for 1 unit of power
 $= 3640 / 186$
 $= Rs. 19.54$

Cost of 1 unit of power from solar panel = $1.97 + 1.78$
 $= 4.25 = Rs. 4 (with profit of 75 paisa per unit)$

The cost of charging an EV for 1 unit using an electric grid is Rs. 4

CONCLUSIONS

The Coimbatore Corporation and LPA is designed mainly using GIS software. The existing 117 petrol tanks in Coimbatore LPA are located and their cost data of 11017 is obtained.

The total electric vehicles (two-wheelers, three-wheelers, and four-wheelers) in Coimbatore LPA by 2030 are estimated as 2,38,554 and the total daily charging demand for these EVs in 2030 is estimated as 14,438 EVs out of which 24.11 % of charge requirement can be met by installing rooftop solar panels in existing tanks.

The optimum number of 274 charging stations including 32 proposed charging stations and the location of such charging stations in Coimbatore LPA are identified. A. The minimum and maximum distance between any two EV charging stations in the grid is 505 km and 7.1 km respectively as per LAMP India scheme 2019.

The typical sustainable charging station located on any highway is plotted and a sustainable 3D model is developed.

Cost estimation of the designed typical charging station is calculated using the approximate cost estimation method. The total cost of the proposed charging station is calculated as Rs. 5,11,80,132 (Three crores Forty-one Lakh Ninety-five Thousand One Hundred and Forty-two) including provision and facilities like a Children's Park, Cafe, ATM, and Toilet. Whereas the cost of a charging station at the Active method (i.e., drawing electricity from the electric grid) is Rs. 2,08,71,132 (Two crores Eighty-eight Lakh Seventy-one Thousand One Hundred and Fifty-two). The cost of charging by using a solar panel is Rs. 3 per kWh, whereas the cost for charging from an electric grid is Rs.9 per kWh. It is also found that solar energy saves Rs. 4 per kWh of electricity in charging costs (i.e., 44.5 % of the charging cost is saved).

The proposed typical charging station has a GREEN building rating of 76 points out of 119 points as per LEED green building rating system standard. Hence the proposed charging station is a self-sustaining charging station.

The methodology adopted in this study is that the optimum location of charging stations can be used in different study areas in the future as well. The design of the typical highway charging station can be commercial and used when designing a charging station in any place in the future as well.

REFERENCES

- [1] Karsakova, Yuliya, "A dynamic GIS model for optimum location identification of plug-in electric vehicle (PHEV) charging stations"
- [2] Conda, Brian, and Cristian, Cristian, "Determination of charging infrastructure location for electric vehicles"
- [3] Handbook of electric vehicle charging infrastructure implementation. NITI Aayog Ministry of Power (MoP), Department of Science and Technology (DST)
- [4] Open Government Data Portal of Tamil Nadu – Information portal
- [5] <https://earth.google.com/web>

Mr. A. Thirugesan, Babu S. Siddharth Krishna, Varunth Rajeev, Rajul Adithyan, Rakshit, Dharmesh Rajhwar and Dhruvi

- [6] IS 6047 – 1971 – Code for functional requirements of hotels, restaurants and other food service establishments.
- [7] IS: 13-2006 Guidelines for Access, Elevation and Layout of Roadside Fuel stations and Service stations.
- [8] Chakrabarti, M. "Estimating, Costing and Specification in Civil Engineering IS-196 – 2000 Indian Standard Plain and Reinforced Concrete – (Code of Practice), Bureau of Indian Standards"
- [9] <https://www.sagepub.org/hand-books/overview>

Configuring pilot Gas Generator with Green propulsion systems.

S. Sankaran
CGRI SMP&TT

Silachitola,
Andhra Pradesh, India

A. Rajarajan
Director AFSC SHA8

Silachitola,
Andhra Pradesh, India

Abstract

With the advent of manned and unmanned missions in space as envisaged by ISRO, development of a new cryogenic, simple and reliable advanced green propulsion system has become a necessity. With increased space budgets, the continuous development of propulsion systems with environment friendly propellants with low emissions has become imperative. This paper presents the development of a pilot scale gas generator based on the hypergolic ignition of ethanediene & hydrogen peroxide with a concentration of $\sim 30\%$ with a catalyst of copper(II) chloride. Open cup drop tests are being conducted to study the effect of amount of metal salt catalyst in fuel and the initial temperature of fuel and oxidant on the ignition delay time. In order to study the viability of the proposed propulsion system, a pilot scale rocket engine is being studied with the hypergolic ignition of monopropellant formation in a real rocket engine environment. A previously fuel Ethanedienol & Hydrogen Peroxide based Rocket Engine (EPRE) has been designed and is under development. This paper deals with the methodology involved in the open cup drop tests, which would give the idea of ignition delay in actual pilot scale rocket engine static testing. Factors, parameters considered for the design of conceptual model of EPRE are being reported. In general, hydrogen peroxide for propulsion grade is being $\sim 80\%$ as reported in literature, whereas, the proposed pilot scale engine uses only $\sim 30\%$ concentration, which is increasing hypergolic value trajectory with the mixture of ethanediene & copper(II)chloride. Hence, it is safer to store the hydrogen peroxide of $\sim 30\%$ concentration, which is stable, compared to $\sim 80\%$. The development of this green propulsion system would cater the requirements of various simulation studies with hot gas or during final including gas dynamic tests, lift-off simulation for various studies, altitude control thrusters, Plasma thruster applications etc.

INTRODUCTION

Low-toxicity storable liquid propellants have become consistently more attractive as possible substitutes for modes of nitrogen and hydrazine. The main benefit of these alternative propellants is the significant cost saving associated with the drastic simplification of the health and safety protection procedures necessary during propellant production, storage and handling. The most promising high-energy green propellants, which are based on simple organic molecules, would compensate for large molecular weight of their decomposition products with high operational temperatures of the exhaust gases are studied by Wadhwa et al & Scherer et al [1&2]. As a consequence, it is necessary to use extremely aggressive materials and manufacturing processes for the thrust chamber and, at the same time, the operational life of the catalytic beds is drastically reduced. Hydrogen peroxide, on the other hand, does not suffer from those disadvantages and has therefore been reconsidered as a promising green propellant for low cost medium thrust applications as demanded by manned and unmanned missions to space in future. Hydrogen peroxide (H_2O_2) is a high density liquid having the characteristic of being able to decompose exothermically in to steam and oxygen according to the following reaction:



The physical properties of hydrogen peroxide would closely match to that of water, with two notable differences. One being, H_2O_2 has a significantly higher density and a much lower vapor pressure. It remains in the liquid state at ambient pressure in a wide range of temperatures. Very importantly, it is relatively easy to handle with respect to other common liquid rocket propellant oxidizers like $TNTO$, nitric acid and liquid oxygen [3]. The propulsive performance of hydrogen peroxide monopropellant rockets is about 20% lower than hydrazine, but the volume specific impulse achievable with 90% H_2O_2 is higher than most other propellants due to its high density. This is particularly useful for systems with significant aerodynamic drag losses. Wernher & Moulton [4] and Wernher & Garfield [5] have

studied the effect of specific impulse with respect to bi-propellant and hybrid rocket engines and observed that hydrogen peroxide based system is yielding a comparable value to other liquid oxidizers.

Further, due to their unique advantages such as active thrust regulation, on/off control capability, and high specific impulse, liquid propellant rocket engines are currently used in long-range applications like space launch operations. With the increase of number of space launches from sea to sea, there have been continuous efforts in developing environmentally friendly liquid propellants with low carbonization but yet with good ballistic performance in terms of high specific impulse and low ignition delay. Hydrogen peroxide is a non-toxic, non-flammable, non-corrosive, non-hazardous propellant with a high density specific impulse. Being non-toxic, H₂O₂ is considered as a green propellant and its popularity is increasing due to the increase of environmental awareness since 1980.

Extensive researches have been done in the past on the use of hydrogen peroxide as a monopropellant, and catalytic decomposition studies comprises a significant percentage of these efforts. Salati et al. [16] have studied many catalysts, which have been considered for hydrogen peroxide decomposition. In hypergolic bipropellant rocket engines, oxidizer fuel and nitrogen tetroxide oxidizer is the most commonly used combination. However, this combination, being highly toxic, poses great health hazards. Since 1990s, researchers have turned out on the development of non-toxic, hypergolic bipropellants containing hydrogen peroxide. US Naval Air Warfare Center Weapons Division at China Lake (NAWC-WD) have developed a green, non-toxic fuel, named Noxol-07, which was hypergolic and completely miscible with H₂O₂ [7]. The fuel is a colloidal suspension of manganese oxide (MnO₂) in methanol. Experimental results showed that reliable hypergolic ignition was achieved for bipropellant containing this fuel and the hydrogen peroxide, but the aging characteristics of the fuel was found to be very poor [8].

The research group at the Purdue University has extensively studied the hypergolic ignition of Noxol-07 fuel, developed by NAWC-WD, and hydrogen peroxide. Poudjpoint [9] & Poudjpoint & Anderson [10] have studied the effects of initial ambient pressure, initial ambient gas properties, and hydrogen peroxide concentration on ignition delay. Drop tests showed that reducing the pressure from atmospheric to 48 kPa led to a 20% increase in the ignition delay for Noxol-07 fuel + 90% H₂O₂ combination. Ignition delay has increased by 50%, when hydrogen peroxide concentration was reduced from 90% to 40% at atmospheric pressure. The effect of catalyst concentration on the ignition delay of Noxol-07 fuel and rocket-grade hydrogen peroxide was studied. The

ignition delay (measured directly from experiments) were about 10 ms for 10% catalyst in methanol and 10 ms for 30% catalyst, showing a decrease in ignition delay with the increase of catalyst percentage [11 & 12].

Mohr & Grubisich [13] have studied a wide variety of fuels with 90% hydrogen peroxide and the only practical hypergolic fuel with hydrogen peroxide was found to be ethanediamine catalyzed with copper (II) chloride (CuCl₂). Kerosene, a commonly used liquid fuel in rocket engines, did not ignite upon contact with hydrogen peroxide, even with the addition of catalyst. Ethanediamine was found to be the best fuel among the many fuels tested due to its high density & low toxicity, reasonable performance, and rapid ignition with hydrogen peroxide [13].

1.1 Scope of the present study

This paper presents the development of pilot scale gas generator based on the hypergolic ignition of ethanediamine & hydrogen peroxide even with a concentration of less than 50% with a catalyst of copper(II) chloride. Open cup drop tests are being conducted to study the effect of amount of metal salt catalyst in fuel and the initial temperature of fuel and oxidizer on the ignition delay time. In order to study the viability of the proposed propellant system, a pilot scale rocket engine is being studied with the hypergolic ignition of bipropellant formulation in a real rocket engine environment.

A pressure-fed Ethanediamine & Hydrogen Peroxide based Rocket engine (EHPRE) has been designed and tested. This paper also deals with the shortcomings involved in the open cup drop tests, which would give the idea of ignition delay in actual pilot scale rocket engine environment. Further parameters considered for the design of conceptual model of EHPRE are being reported. In general, hydrogen peroxide for propulsion grade is being > 90% as reported in literature, whereas, the proposed pilot scale engine uses only < 50% concentration, which is becoming hypergolic, when mixture with the mixture of ethanediamine & copper(II)chloride (CuCl₂). Hence, it is safer to store the hydrogen peroxide of < 50% concentration, which is stable compared to > 90%. The experiments conducted with the EHPRE and the peak chamber pressure / Temperature with various concentrations of Catalyst are reported in this paper.

2.0 Development of a Pilot scale Ethanediamine & Hydrogen Peroxide based Rocket Engine (EHPRE)

2.1. Open cup drop tests

These tests are done essentially to determine the decomposition delay, as it is one of the critical parameter for hypergolic propellant rocket motors, as it determines the design of nozzles, starting nozzles and is very critical

application limitations (following multiple starts and stops to meet mission requirements). In this paper, an experimental investigation of hypergolicity and its decomposition delay of fuel mixture with Hydrogen Peroxide are presented. Also, example results of high speed photography from drop tests are shown here. Open cup drop tests were conducted at atmospheric pressure to measure the decomposition delay times of different mixtures of ethanolanine Cof12 with hydrogen peroxide of concentration ranging from 50 % to 90%. The schematic of the set up is shown in Fig. 1. In drop tests, 3 ml fuel/oxidizer mixture was put into a glass cup as shown in Fig.2. Then, a drop of hydrogen peroxide was added into this cup using a glass syringe/needle. The tests were recorded with a digital high-speed camera of 1000 frames/second (FPS) and the time period from the instant that the first H₂O₂ drop reached the fuel surface to the moment that the instantaneous flame appeared was defined as the decomposition delay time. From the results, it is learnt that two mixtures, each using commonly available oxides and transition metal compounds would result in the delays on the order of 20 milliseconds.

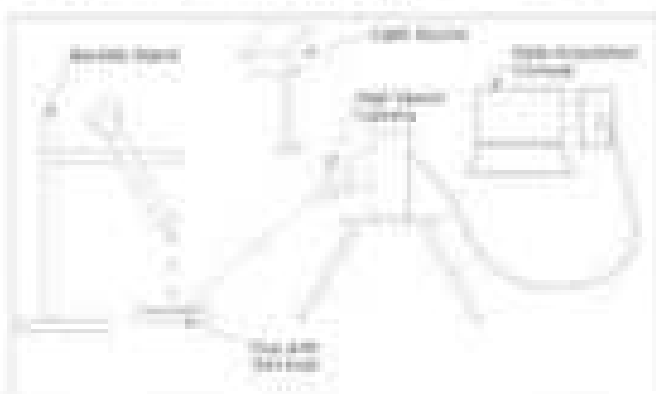


Figure 1: Schematic of the open cup drop test set-up



Figure 2: View of the open cup drop test set-up

The following Table-1 gives the delays obtained for different cases using the above experimental set-up. It is observed that when the fuel mixture of Ethanolanine and Copper (II) chloride is preheated to 70°C, the delay in decomposition has reduced from 26 milliseconds to 14 milliseconds when compared with room temperature fuel mixture. Further, the delay reduces as the concentration of H₂O₂ increases. The reasons for the different delays obtained for different fuel mixture and oxidizer cases are due to fluid contact control surface, mixing phenomena, kinetics, heat transfer, initial temperature, ambient pressure and other local environmental conditions.

Table-1 Open Cup Drop test De-composition delays obtained for various cases of Fuel/H₂O₂ mixtures

Case	Concentration of H ₂ O ₂ (%)	Temperature of Ethanolanine mixture (°C)	Mode of Ignition	Decomposition delay (ms)
Case-1	50 %	Room Temp.	Normal (20°C)	27 ms
Case-2	50 %	70 °C	Normal (20°C)	27 ms
Case-3	50 %	70 °C	Normal (20°C)	26 ms
Case-4	90 %	70 °C	Normal (20°C)	14 ms

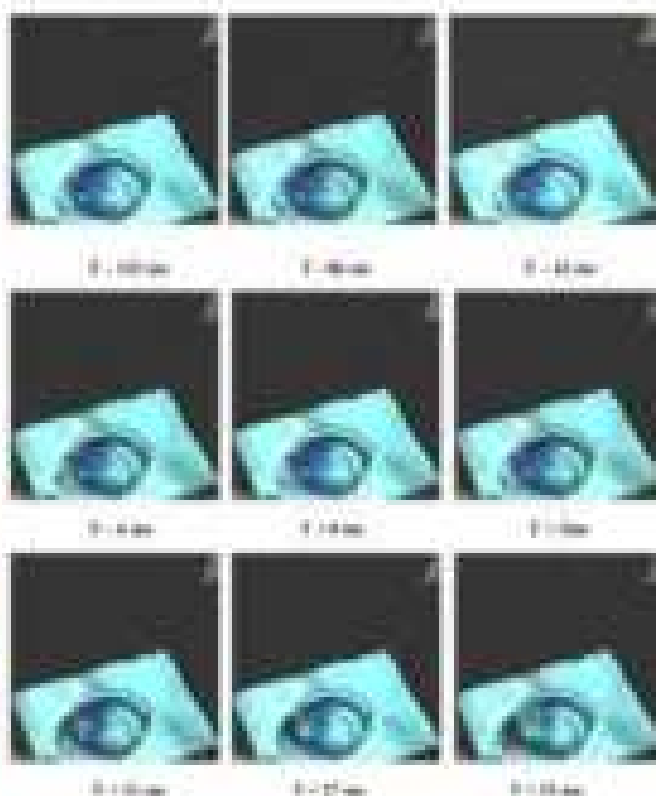


Figure 3: Time history of hypergolic decomposition delay for 50 % concentration Hydrogen peroxide droplets and Ethanolanine mixture using high speed digital photography

2.2 Fuel/Oxidizer (F/O) Air Ratio computation

For example, balanced combustion reaction for the mixture of 50% concentrated Hydrogen Peroxide with Ethanolamine in presence of Copper (II) Chloride is given below.



Hydrogen Peroxide exothermally reacts with ethanolamine and liberates energy. From the above balanced chemical reaction stoichiometric mass of the products can be written as:



From the above equation, it can be computed that for 1kg of fuel (Ethanolamine), 394 g of 50% concentrated H_2O_2 (Oxidizer) is required, which is resulting in M_2/M_1 of 0.39. For a gas pressure with a mass flow requirement of 0.5 kg/s, the oxidizer and fuel required are 0.437 kg/s of 50% concentrated H_2O_2 and 0.997 kg/s of Ethanolamine with Copper (II) chloride mixture.

2.1 Schematic of EHPRE configuration:

From the open cup drop test, the fuel and oxidizer are found as 50 % concentration Hydrogen peroxide and Ethanolamine with Copper (II) chloride. With fuel-oxidizer ratio 1:0.39, where as the Ethanolamine and transition metal compound is of the proportion of 10:1. With this known configuration, a pilot EHPRE with 0.5 kg/s flow rate has been designed. The following is the schematic of the pilot engine (Fig.4). The P&I diagram for the demonstration of EHPRE is shown in Fig.5. The subsequent sections will deal with injector design, combustion chamber, nozzle configuration, instrumentation provided etc.

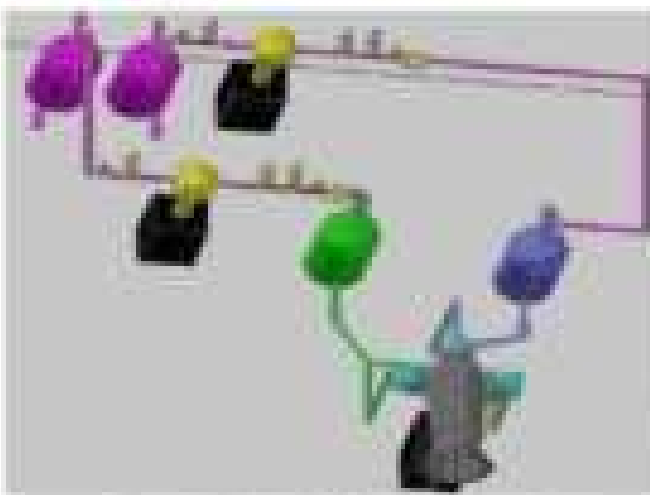


Figure 4: View of pilot scale EHPRE

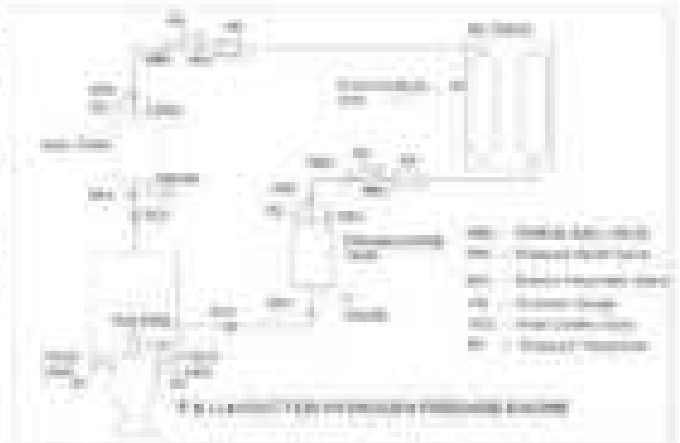


Figure 5: P&I diagram for the Pilot EHPRE Demonstration

2.4 Design of Fuel and Oxidizer injectors:

The fuel and oxidizer are stored as 50 % concentration Hydrogen peroxide and Ethanolamine with Copper (II) chloride with fuel-oxidizer ratio 1:0.39, where as the Ethanolamine and transition metal compound is of the proportion of 10:1. From the balanced reaction, 10:1 ratio of oxidizer is required for the stoichiometric combustion of 1 mole of fuel. To compute the orifice diameter dimensions for the oxidizer injector, the following expression is used based on mass rate:

$$m = n C_d \rho A V \quad (4)$$

Where, n is the number of orifices ($n=2$), C_d is the coefficient of discharge, assumed to be 0.6, ρ is the density of Hydrogen Peroxide (1200 kg/m³), A is the area of individual orifice and V is the velocity of the oxidizer jet (at 25 bar pressure). Based on the computation, the orifice dimension is arrived to be 2.1 mm. Similarly, the computation of fuel injector orifice dimension was carried out and the diameter of fuel injector was derived to be 1.15 mm (for number of orifice = 2).

2.5 Calculating the Chamber Length:

The combustion chamber length was designed for a nozzle throat diameter of diameter of 17.5 mm. The parameter L^* is the characteristic length ($L^* = V_c/A_t$) for H_2O_2 is 325 mm. The length of the combustion chamber is computed using the relation, $V_c = 1.1 A_t L_c$, where, V_c is the volume of the combustion chamber and A_t is the area of the

combustion chamber. The length (L_c) of the combustion chamber with A_c/A_t of 5 (from literature) is computed to be 90 mm, whereas, the diameter is computed to be 39 mm (D_c).

2.6 Nozzle Calculations:

A pilot scale EHPR is designed for 0.54 kg/s flow rate through the nozzle with a stagnation pressure of 14 bar. The expected stagnation temperature is about 500 K with a specific heat ratio of 1.23. However, it will be verified based on the nozzle exit pressure measurement later during the test. Value of the specific heat ratio was taken from the NASA GLPFC Chemical Equilibrium Analysis. Assuming isentropic combustion and equilibrium in the reaction chamber temperature for 70% pure H_2O_2 with Ethanolamine is in the order of 1500 K. The temperature varies down with reduction in the purity of H_2O_2 .

2.6.1 Calculating Area of the nozzle throat & exit Mach number:

The average molar mass of 70% Hydrogen Peroxide is 20.87 g/mol. The following expression of $m = C_t \cdot P_t \cdot A_t$ is used wherein m is Mass flow rate through the throat, P_t is the stagnation pressure in the chamber and A_t is the throat projected area. A perfectly expanded nozzle is chosen for experiments. Nozzle exit mach number is computed to be 2.43 and the Area ratio ($A_e/A_t = C$) is computed as approximately 4.0 from the standard nozzle relation.



Fig.6 Sectional view of the EHPR pilot model

2.6 Uncertainty considerations in Experimental determination of Decomposition Delay:

In general, drop size experiments are being conducted with various forms of high speed video imaging. The setup described in this paper could afford larger details for observations during the test. As previously noted, a consideration for performing drop sizing is the precision uncertainty, or repeatability of replicated experiments. In this case it was decided to evaluate test parameters such as drop volume, drop height, single drop, multiple drops, droplets coalesce into the fuel to maintain a measure of sensitivity of parameters involved in the experiment. The above might cause large precision uncertainty on the order of 10% of nominal values, with some anomalies less resulting in lower decomposition delays. Further review of this method with rapid decomposition of fuel and oxidant using high resolution camera (1000 FPS) could reveal that, these experiments have sufficiently low bias uncertainty. However, during the testing of pilot scale EHPR, the exact decomposition delay will be measured and the parameter will be compared with the mean drop test results.

2.6 Results and Discussion:

Experiments are carried out with the modified pilot scale per parameters. Concentration of the Hydrogen peroxide is limited to 50% and the metal catalyst Copper II Chloride was varied from 10% to 1% in the experiments. From the experimental data it was observed that at 5% concentration of Copper II Chloride higher chamber temperature was recorded and the chamber pressure was comparable with that of 10% concentration catalyst. Results of the experiments are shown in Table 1. But with lower concentration of $CuCl_2$, the rate of reaction is very low that the experiments were not higher.

Table 1. Experimental results with various concentrations of Catalyst.

Exp no.	Configuration		Results		Pressure of test (bar)
	H_2O_2 conc.	$CuCl_2$ Concentration (%)	P_c (bar)	T_c (K)	
1	10	10	13.8	440	0
2	10	10	13.45	400	0
3	10	5	12.7	400	0
4	10	2	12.5	350	0
5	10	0	12.9	410	0
6	10	0	14.0	380	0
7	10	0	14.7	340	0
8	10	0	0.5	310	0
9	10	0	0.2	310	0

5.8 Conclusion

In this study the hypergolic ignition of rhodamine based Hydrogen Peroxide liquid engine has been designed with sufficiently low concentration of H_2O_2 (30%), with metal catalyst of copper (II) Chloride for the first time in rocket engine and this catalytic application. Even low concentration Hydrogen Peroxide can be mixed with fuel mixture with transition metal catalyst, which is clearly established based on open cup drop tests to provide hypergolic propellant combinations, with a decomposition delay of 75ms, using high speed digital imaging system. Pre-heating of fuel mixture could reduce the delay further. Based on the open cup drop test, it is envisaging that the combination of Rhodamine with H_2O_2 can be a potential fuel oxidizer combination. Hence, experiments with like on or-like injection were carried out and combustion was observed. With increase in the concentration of H_2O_2 the possibility of generating higher chamber temperature exists.

Future Scope

Development of Hydrogen peroxide autocatalytic to enable the H_2O_2 to rocket grade can be initiated towards development of green propulsion systems. Further the with the present fuel Hydrogen peroxide based rocket engine can be utilized as a high pressure high temperature gas generator.

6.0 References

- [1]Wachover E. L, Christofferson S. and Reed B. "Assessment of High Performance HAN Monopropellant", AIAA paper No. 2009-2472, 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Huntsville, Alabama.
- [2]Schroyer H.F.R., Keating P.A.G.C., Vithanas W.I.L.M., Lammert J., Heijden A.E.D.M., Kelders H.L.A. and v.d. Berg R.F., "An Overview of the Development of HNF and HNT-based Propellants", AIAA paper No. 2040- 2561, 46th AIAA/ASME/SAE/ASST Joint Propulsion Conference, Huntsville, Alabama.
- [3]Vaethen M. and McLean P., "The Use of Hydrogen Peroxide for Propulsion and Power", AIAA paper No. 99-2080, 35thAIAA/ASME/SAE/ASEE Joint Propulsion Conference, Los Angeles, California.
- [4]Wernikow E. and McLean P "Recent Developments in Hydrogen Peroxide Monopropellant Devices", AIAA paper No. 1999-2741, 35th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, LA, California.
- [5] Wernikow E. and Garboden G., "Experimentation with Hydrogen Peroxide Oxidized Fuelers", AIAA paper

No. 1999-2741, 35th AIAA / ASME/SAE/ASEE Joint Propulsion Conference, LA, California.

- [6]Salim IA, El Mousawi M, Zaki AB. "Kinetics and mechanism of decomposition reaction of hydrogen peroxide in presence of metal complexes". International Journal Chemical Kinetics 2009;32(1):643-66.

- [7] Meeke, C.J, Larmann, B. Parrell, N.E. "Status of nanoscale hypergolic reusable fuel development at NASA/WDI Churn Lake", In Second International hydrogen peroxide propulsion conference: 1999

- [8] Parrell N, Dine A, Muthart M. "Test results of new reduced-toxicity hypergols for use with hydrogen peroxide oxidizer" In 4th international hydrogenperoxide propulsion conference: 1997.

- [9]Pierpoint T.L. "Hypergolic ignition of a catalytically promoted fuel with metal peroxide/hydroperoxide," PhD thesis, School of Aeronautics and Astronautics, Purdue University, USA, December 2003.

- [10]Pierpoint T.L., Anderson W.E. "Environmental effects on hypergolic ignition" 43rd AIAA/ASME/SAE/ASST joint propulsion conference and exhibit, Arizona, USA: 29-13 July 2003. AIAA Paper No.: 2003-1581.

- [11]Frolik S. "Hypergolic liquid fuels for use with rocket grade hydrogen peroxide" M.S. thesis, School of Aeronautics and Astronautics, Purdue University, USA: August 2001.

- [12] Frolik S, Austin HJ, Smith JJ, Hunter SD. "Development of hypergolic liquid fuels for use with hydrogen peroxide." AIAA 2005-1044.

- [13]Mihal BM, Gendrich MC. "Investigation of hypergolic fuels with hydrogen peroxide", AIAA 1991-1817.

GCDI - 2023

Abstracts

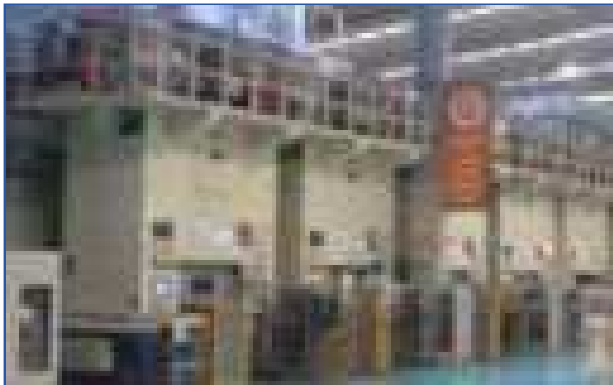




BARANI HYDRAULICS INDIA PRIVATE LIMITED

An Indian solution provider with International reputation

Barani is the leading Custom build hydraulic press manufacturer and exporters in India having more than 3 decades of accumulated and self-made experience in machine building and providing total solutions for customer requirements focusing on Industry 4.0 concepts and Artificial Intelligence (AI) features. Track record by supplying presses for over 100 corporate companies within India and around 30 overseas customers



HYDRAULIC PRESS MANUFACTURING DIVISION

- More than 3 decades of expertise in customized hydraulic machine building around 3650 installations both domestic & overseas
- Capacity 5 Tons to 3600 Tons
- Exported to 18+ countries
- Pioneer in manufacturing servo hydraulic press
- Presses with Robotic & Transfer Line Automation

SHEET METAL COMPONENT MANUFACTURING DIVISION

- Sheet metal components ranging more than 3000+
- 70+ New developments everymonth
- Capacity – 30,000 nos / month; Spare capacity – 18,000 nos / month
- Press Shop – Hydraulic presses – 5 nos (upto 1500T), Mechanical press
- Paint Line - Semi-Automated – 1 no and overhead conveyor paint booth – 1no



ASSEMBLY PRODUCTS MANUFACTURING DIVISION

- Dedicated actuator and mounting kit assembly unit
- More than 2000 assembly product ranges
- Supplying to domestic and 15+ Global manufacturing sites

MECHANIZED FOUNDRY DIVISION

- Manufacturing all grades of Grey & Ductile Iron castings
- Semi-Automated facility with DISA equipment
- Production capacity – 700 Tons / month



Strategic supply Partner for
7+ Global Market Leaders

GCDI_23101
Energy Recovery Devices for Desalination

Manikandan Sakthivel
SLB, Tidel Park, III Floor,
Villankurichi Rd, Civil Aerodrome
Post, Coimbatore - 641014
MSakthivel@slb.com

ABSTRACT

Seawater desalination has swiftly emerged as an indispensable source of potable water in numerous regions worldwide. Ensuring the efficiency of pumping systems is crucial for reliable desalination processes. Energy Recovery Devices (ERDs) play a pivotal role in enhancing energy efficiency. The growing challenge of water scarcity has emerged as a significant obstacle to both social progress and economic growth, with this critical worldwide concern facing escalating threats due to human actions and the effects of climate change. Projections suggest that by 2030, the global demand for water will exceed the sustainable supply of freshwater sources by a staggering 40%. Consequently, there has been a substantial surge in research and exploration of seawater desalination technologies aimed at harnessing freshwater from the boundless oceans. According to research findings, the desalination market is experiencing robust growth. At present, reverse osmosis (RO) technology accounts for approximately 65% of the total desalinated water production, primarily owing to its inherent benefits such as cost-effectiveness and energy efficiency. Within the RO desalination process, a significant portion of the total cost is attributed to electrical energy, with approximately half of this energy consumption directed toward achieving high-pressure feed water. Given that more than half of the feed water is discharged as brine at high pressure after the RO process, various types of energy recovery devices (ERDs) have been continuously developed to recycle the high-pressure energy stored within the brine. The adoption of ERDs stands as a pivotal factor in reducing energy consumption to its current levels, contributing to the dominance of seawater reverse osmosis (SWRO) in the desalination market.

GCDI_23102
Revolutionizing Maritime Transport: A Blueprint for Sustainable Mobility - Conceptualizing an Electric Roll-On/Roll-Off (RO-RO) Ferry System for India's National Waterway 3

Aravind K R
Department of Ship Technology, Cochin
University of Science and Technology, Kochi 22, Kerala, India
aravind@cusat.ac.in

C B Sudheer
Department of Ship Technology, Cochin
University of Science and Technology,
Kochi 22, Kerala, India

ABSTRACT

Maritime transportation is a pivotal point in global trade, underpinning economic activities across the globe. However, the reliance on conventional diesel-powered ferries raises pressing environmental concerns, from air pollution to greenhouse gas emissions. This paper endeavours to chart a sustainable and innovative course by presenting a comprehensive concept design for an electric Roll-On/Roll-Off (Ro-Ro) ferry tailored explicitly for National Waterway 3 in India. The study delves deeply into the feasibility, potential environmental impact, and economic viability of transitioning to an electric Ro-Ro ferry system. By focusing on this specific waterway and considering a prototype ship which is in service, the paper addresses localized concerns but also contributes to the broader conversation about adopting green solutions in maritime transportation.

GCDI_23103**Decarbonising India through Sustainable Consumption – An Analysis of Customer Awareness, Availability and Adoption of Panchagavya Products**

Dr D Divya prabha
Associate Professor
Department of Management Sciences
PSG College of Arts & Science,
Coimbatore
divyaprabha@psgcas.ac.in

ABSTRACT

The increasing concern for environmental safety and global demand for pesticide residue free food has evoked keen interest in using eco-friendly products. Panchagavya an ancient traditional medicine in India has been used to treat various diseases in a natural and traditional manner to lead a healthy life. Panchagavya refers to the five cow products such as milk, urine, dung, curd and ghee are rich in nutrition, amino acids, proteins, vitamins, minerals, and hormones. These products are known to cure several human diseases and enhance immune power of humans, animals, and even the environment. With today's customers seeking holistic solutions to address physical, mental, and spiritual aspects of wellbeing, the demand for sustainable products are increasing for a variety of reasons ranging from cultural and traditional beliefs to health and sustainability considerations. Among the different sustainable products, panchagavya products derived from natural source is available in the market. This research paper analyses the awareness, availability and adoption of the different panchagavya products available in the market.

GCDI_23104**CO₂ Dehydration for CCUS**

Venkatesan Jayaraman
SLB, Tidel Park, III Floor,
Villankurichi Rd, Civil Aerodrome
Post, Coimbatore - 641014
vjayaraman3@slb.com

ABSTRACT

In recent years, the oil and gas industry has been facing challenges in developing and operating high-CO₂ content fields. The CO₂-rich streams, separated from the produced natural gas especially from AGU/SRU, can be injected to depleted/pressure reduced wells for enhance oil recovery from the reservoirs. Even in cases where the oil recovery increase is not so significant, operators have to consider the CO₂-rich stream compression and injection, in order to avoid its venting to the atmosphere.

GCDI_23105**Study on Consumer Behaviour on Refashioning Hand-Me-Down Sarees as an Advancing Circular Fashion Practice**

Karuvelaselvi

Lecturer, Department of Apparel Technology,
PSG Polytechnic College, Coimbatore, India
rks.dat@psgpolytech.ac.in

R Thenmozhi

Independent researcher
thencdf@gmail.com

ABSTRACT

This research paper aims to explore the consumer behaviour associated with refashioning hand-me-down sarees into customer-intended items. The study investigates the motivations, preferences, and decision-making processes of consumers who engage in this practice. By examining the factors that influence consumers to repurpose traditional garments, this research seeks to provide insights into sustainable fashion consumption patterns and contribute to a more circular economy. The findings of this study will offer valuable implications for marketers and designers in promoting sustainable fashion practices and encouraging consumers to adopt more conscious consumption behaviours

GCDI_23108**Development of Innovative Forming Process for Automotive Body Parts to Reduce Emission and Energy Consumption**

D Rajenthirakumar

Department of Mechanical Engineering,
PSG College of Technology, Coimbatore
drk.mech@psgtech.ac.in

A Arudhra Surya

Department of Mechanical Engineering,
PSG College of Technology, Coimbatore

V M Himassai Ganesh

Department of Mechanical Engineering,
PSG College of Technology, Coimbatore

S Aruneshwar

Department of Mechanical Engineering,
PSG College of Technology, Coimbatore

ABSTRACT

To reduce emission of carbon dioxide and energy consumption in automotive industry, light metals are increasingly used for body parts. Due to their poor ductility at room temperature light metals such as magnesium alloys and titanium alloys are difficult to deform. It is necessary to deform them plastically at elevated temperature. Because of their high thermal conductivity, heating method before or during forming is very important in forming of those materials. In forming of these alloys sheets, heating in a furnace before forming is not suitable because the sheet temperature is easy to cool down and another heating method is required. Incremental sheet metal forming process is a dieless forming process and it can be called one kind of 3D printing in sheet metal forming. Since incremental forming process necessitates very long time especially in manufacturing large size products, the sheet should be heated during forming. In this work, to form hard-to-work metal sheets without heating using energy sources such as furnaces, torches and laser beams, a new dieless digital forming process, called friction stir incremental forming process is developed. The behavior of titanium (hard-to-form material) formability is investigated using friction stir incremental forming process in which forming is done under localized friction heating caused by high tool rotation (without the use of dedicated dies). This work focuses on improving the mechanical properties (like hardness, yield strength and tensile strength) through process optimization. Series of experiments are carried out in a vertical machining centre with grade 5-Ti-6Al-4V alloy sheets of size 300 mm x 300 mm x 1.2 mm with hemispherical end forming tool. The effect of key process parameters, namely the rotation speed, the feed rate and the step depth is investigated. This work addressed the key issues encountered by researchers worldwide on friction stir incremental forming and it will provide useful guidance in improving the product quality thereby reducing energy consumption of automotive parts.

GCDI_23109
**Designing and Experimental Analysis Of Dye Sensitized Solar Cell Using
Titanium Dioxide and Natural Dye**

Mr Krishna A S
Ph.D. Scholar – Faculty of Electrical Engineering, Hindusthan Institute of Technology, Coimbatore
krishna.msbarathi@gmail.com

Prof Kokilavani S
Principal, Hindusthan Polytechnic College, Coimbatore
vani.msb@gmail.com

Ms Narmadha A S
Assistant Professor, Department of ECE, Hindusthan Institute of Technology, Coimbatore
narmadha.asn@gmail.com

ABSTRACT

This study explores the design and experimental analysis of a solar cell utilizing titanium dioxide (TiO₂) as the semiconductor material and natural beetroot dye as the photosensitizer. The investigation encompasses the fabrication of a dye-sensitized solar cell (DSSC) by depositing a TiO₂ film on a conductive glass substrate. The natural dye extracted from beetroot is employed to sensitize the TiO₂, harnessing its light-absorbing properties. The DSSC is assembled by sandwiching the TiO₂-coated glass with a counter electrode and an iodide-based electrolyte. Experimental measurements of open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}) are conducted, and current-voltage (I-V) characteristics of the solar cell are analyzed under varying light conditions. The results demonstrate the feasibility of using natural beetroot dye as a photosensitizer in DSSCs and provide insights into the performance of such eco-friendly solar cells, contributing to the field of sustainable energy technologies. Keywords – Renewable

GCDI_23111
**Proton Exchange Membrane Fuel Cell:
A Computational Study of Bi-Polar Plate (BPP) Design Concepts**

R Bhoobathi
Research Scholar, Department of Automobile Engg,
PSG College of Technology, Coimbatore
Email: boopathisam16@gmail.com

Dr P Karthikeyan
Professor, Department of Automobile Engg,
PSG College of Technology, Coimbatore
Email: apk.auto@psgtech.ac.in

ABSTRACT

Bipolar plates are a crucial component of proton exchange membrane fuel cells. They are responsible for transporting reactant gases, carrying the current from the membrane electrode assembly to the end plates, providing heat and water management, and separating the individual cells. However, these plates also contribute to 80% of the fuel cell's weight, 50% of its volume, and 40% of its cost, posing a barrier to the commercialization of fuel cells. In a PEMFC stack, metallic bipolar plates (BPP) are compressed at 15 - 20 bar (1.5- 2 MPa) pressure with gas diffusion layers (GDL) to maintain good electrical contact. The patent trend of BPP shows improvement of production (moldability, material flowability), electric conductivity, and production by die equipment, etc., even though it has other parameters like strength, gas permeability, bonding, heat resistance, flexibility & hydrophilic., etc. This paper provides a comprehensive review of BPP design considerations and initial numerical evaluation trajectory for 'BPP manifold flow path' design suggestions for 1 kW- PEM fuel cell stack level maturity.

GCDI_23113**An experimental study on variable speed fan cooling for hydrogen fuel cell application**

Kirthik Anand
PG Student,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore, India
krithikanand32@gmail.com

Dineshkumar Ponnaiyan
Research Scholar,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore, India
dineshponnaiyan@gmail.com

Kirthik Anand
PG Student,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore, India
krithikanand32@gmail.com

Vijai Kaarthi Visvanathan
Research Scholar,
Department of Automobile Engineering,
PSG College of Technology, Coimbatore, India
vijaiikaarthivexam@gmail.com

ABSTRACT

In this article, we have investigated the transient thermal behaviour of fuel cell under variable fan speeds. To determine the temperature generated in the fuel cell stack, the stack is tested under variable load points. The temperature profiles for three different cases in the fuel cell stack are evaluated. Findings indicates that controlled cooling through variable fan speed approach yields better results while maintaining the temperature of the stack at the desired range. This approach reduces the parasitic load on the stack, and hence improves the overall performance.

GCDI_23115**Electric Vehicle Battery Pack Cooling Using Predictive Control Strategy Under Different Driving Conditions**

Vijai Kaarthi Visvanathan
Research Scholar, Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
vijaiikaarthivexam@gmail.com

Karthikeyan Palaniswamy
Professor, Department of Automobile
Engineering, PSG College of
Technology, Coimbatore
apk.auto@psgtech.ac.in

Dineshkumar Ponnaiyan
Research Scholar, Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
dineshponnaiyan@gmail.com

Boopathi Rathinam
Research Scholar, Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
Bhoobathi.Rathinam@in.bosch.com

Parthiban M
Undergraduate Student, Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
20a221@psgtech.ac.in

Sakthivel R
Undergraduate Student Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
20a225@psgtech.ac.in

Ramesh S
Undergraduate Student Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
20a227@psgtech.ac.in

Sanjai Kumar S
Undergraduate Student Department of
Automobile Engineering, PSG College
of Technology, Coimbatore
20a228@psgtech.ac.in

ABSTRACT

Electric vehicle (EV) adoption is growing at an amazing rate. The battery packs that these vehicles carry are their lifeblood, and excessive heat can limit their performance. Charging and discharging performance can be limited by thermal constraints. Heat exposure can limit the range and life of battery packs. The thermal time constant of larger battery packs is long and, thermostatic cooling models can be too slow, as they may first cool the pack when it already has a large amount of thermal energy. Predictively cooling the pack based on expected thermal demands can help keep it near its optimal temperature range. This can allow faster charging and discharging, longer range, and extended battery life. A dynamic electric vehicle cooling model will be developed. The electric vehicle model will use fast acceleration and driving cycle load to imitate the different real-time driving conditions. A predictive controller has to be developed to control the cooling of the battery pack. The controlled battery temperature and the other parameter variations are studied through the control strategy implementation and by comparing two liquid coolants.

GCDI_23118

Removal of Fermentation Inhibitor to Maximize the Bioethanol Production

Dr K Chandrakumar
Associate Professor
DREE, AEC & RI,
TNAU, Coimbatore 3
chandrakumar@tnau.ac.in

Dr S Sriramajayam
Professor
DREE, AEC & RI,
TNAU, Coimbatore 3
ramajayam@gmail.com

Dr V Palaniselvam
Professor
DREE, AEC & RI,
TNAU, Coimbatore 3
palaniselvamv@tnau.ac.in

Dr D Ramesh
Professor & Head
DREE, AEC & RI,
TNAU, Coimbatore 3
rameshd@tnau.ac.in

ABSTRACT

The production of alternative liquid transportation fuels (ethanol) from biomass has shown great promise towards reducing our dependence on petroleum. The sugars derived from biomass are used for the production of ethanol. Glucose and xylose upon degradation during the pretreatment conditions produces 5- hydroxymethylfurfural (HMF) and furfural, respectively. The removal and purification of inhibitory compound namely furfural is an important step in the bioethanol production. Acid pretreatment of Paddy straw were carried out using different concentrations of HCl and H₂SO₄ and furfural content was quantified using HPLC. The removal of furfural was carried out using the amberlite resins like XAD4 and XAD7. The amberlite resin XAD4 was found to be more efficient (98%) than XAD7 in the removal of furfural (83%) after the pretreatment of paddy straw. Thus, the removal of furfural during acid pretreatment of paddy straw will enhances the bioethanol production.

GCDI_23119

Development of Evacuated Tube Solar Air Heating System for Drying Grapes

P Vijayakumary
Department of Renewable Energy Engineering, Tamil Nadu
Agricultural University, Coimbatore
vijayakumarybioenergy@tnau.ac.in

J Gitanjali
Department of Renewable Energy Engineering, Tamil Nadu
Agricultural University, Coimbatore
jogitanjali@gmail.com

S A Ramjani
Department of Renewable Energy Engineering, Tamil Nadu
Agricultural University, Coimbatore
kadeeja_ram@yahoo.co.in

D Ramesh
Department of Renewable Energy Engineering, Tamil Nadu
Agricultural University, Coimbatore
rameshd@tnau.ac.in

ABSTRACT

Drying plays an important role in processing and preservation of agricultural produce. Drying avoids the growth of microorganisms thereby retains the quality and enhance the shelf life of the products. In this research work an evacuated tube collector (ETC) solar dryer is designed and developed for drying seedless grapes. The collector and dryer are designed based on the sample size, i.e. 5 kg of the grapes and on the criteria of collector surface to volume of dryer ratio. Performance analysis of this system is done on analytical and experimental basis. During the experiment, temperatures of hot and cold air at various places, ambient relative humidity and humidity variation in drying chamber, wind velocity and mass of the grapes are measured throughout the tests on an hourly basis. Average thermal efficiency of the air heating system was found to be 31 per cent. The desired moisture content of 20% from an initial moisture content of 80% of grapes was reached within 7 days when dried using evacuated tube solar air collector compared to 20-22 days in open sun drying method.

GCDI_23121
Recent Trends on Climate Impact of Plastics and
Exploring Sustainable Alternative for a Greener Future

P M Surendar
PG Scholar,
Department of Mechanical Engineering,
PSG College of Technology, Coimbatore
22md03@psgtech.ac.in

Iniyan K
PG Scholar,
Department of Mechanical Engineering,
PSG College of Technology, Coimbatore
22md02@psgtech.ac.in

Prabu T
Professor,
Department of Mechanical Engineering,
PSG College of Technology, Coimbatore
tpr.mech@psgtech.ac.in

ABSTRACT

Plastics have become an integral part of modern society, offering versatility and convenience in various applications. However, their widespread use has led to severe environmental repercussions, including climate change. This abstract provides an overview of the climate impact of plastics, shedding light on the often-overlooked connection between plastic production, use, and their contribution to greenhouse gas emissions. The production of plastics, predominantly derived from fossil fuels, is an energy-intensive process that releases substantial quantities of greenhouse gases, particularly carbon dioxide (CO₂). Moreover, the extraction and transportation of the raw materials required for plastic production further exacerbate emissions. As the demand for plastics continues to surge, these emissions are on an upward trajectory. Beyond the initial emissions associated with production, the climate impact of plastics extends throughout their lifecycle. Plastics do not readily decompose, and when disposed of in landfills or incinerated, they release additional CO₂ and other harmful gases into the atmosphere. Microplastics, resulting from the breakdown of larger plastic items, also contribute to the climate crisis, as they absorb and transport heat in marine environments, affecting oceanic ecosystems and weather patterns. Furthermore, the environmental consequences of plastic pollution, such as habitat destruction and disruption of natural carbon cycles, indirectly exacerbate climate change by impairing ecosystems' ability to sequester carbon and maintain climatic stability. The main focus of this study is the urgent need to address plastic's influence on the climate. Strategies such as reducing plastic production, promoting recycling and circular economy models, and developing sustainable alternatives can mitigate the emissions associated with plastics. Additionally, raising awareness among consumers and policymakers about the interconnectedness of plastics and climate change is crucial to drive meaningful change. In conclusion, understanding the climate impact of plastics is vital for mitigating the broader environmental challenges we face. By recognizing plastics' role as both a contributor to and a victim of climate change, we can work toward a more sustainable and resilient future.

GCDI_23123
Metropolitan Strategies of Advancing Decarbonization Across India

Karthikeyan R
M.E -Engineering Design, PSG college of technology
Email: 22md31@psgtech.ac.in

Dr Prabu T
Professor, PSG college of technology
Email: tpr.mech@psgtech.ac.in

ABSTRACT

Decarbonizing Buildings in Cities and Regions aims to identify best practices and challenges for both national and subnational governments in driving the decarbonization of buildings. India being the third-largest emitter globally, emitting a net 2.9 gigatons of carbon dioxide equivalent (GtCO₂e) every year as of 2019. The bulk of these emissions (about 70%) are driven by six sectors namely power, steel, automotive, aviation, cement, and agriculture. The reduction of Carbon dioxide emissions or Decarbonisation can be achieved with a focus on three important areas such as Increasing renewable energy capacity, Decarbonising emission-intensive sectors such as transportation, power generation, building/infrastructure sector, cement and construction sector, and creating more carbon sinks. This paper investigates different aspects of smart city development and introduces new feasible indicators related to the six sectors and existing barriers to smart city development, and solutions to overcome them. The findings indicate that the successful integration of smart buildings into smart cities requires attention to multiple factors related to smart energy, smart mobility, smart water, smart security, and smart waste management infrastructures.

GCDI_23124**Green Technology Minimizing Carbon Footprint for Lubricants**

Yashwanth Kumar S
ME Engineering Design,
PSG College of Technology
Email: 22md11@psgtech.ac.in

Dr Prabu T
Professor,
PSG college of technology
Email: tpr.mech@psgtech.ac.in

ABSTRACT

The transition towards a sustainable and environmentally friendly future requires a comprehensive evaluation of alternative technologies and materials. Lubricants play a crucial role in various industrial processes and transportation sectors, and their environmental impact is of increasing concern. This paper presents an in-depth comparative study of green technology and traditional-based lubricants to determine their respective carbon footprints and overall environmental performance. The study aims to provide valuable insights into the potential benefits of adopting bio lubricants as a green technology solution for reducing carbon emissions in various applications.

GCDI_23125**Green Technology Initiatives and Government Policies:
Driving ESG Compliance and Carbon Reduction in India**

Vijay E
M.E -Engineering Design,
PSG college of technology
Email: 22md10@psgtech.ac.in

Dr Prabu T
Professor,
PSG college of technology
Email: tpr.mech@psgtech.ac.in

ABSTRACT

India, one of the world's fastest-growing economies, faces substantial environmental challenges due to its rising carbon emissions and pollution levels. This paper provides a comprehensive review of green technologies with a specific focus on India and their potential to mitigate the current status of the carbon footprint in the country. It examines various sectors, including energy, transportation, agriculture, and waste management, to explore the innovative solutions that have emerged to address these issues. The paper evaluates the effectiveness and feasibility of these technologies in the Indian context, taking into consideration the unique socioeconomic and environmental factors of the country. Additionally, it delves into the Government initiatives and policies aimed at reducing carbon emissions, the policy and regulatory challenges faced, and the role of public-listed companies in adopting ESG (Environmental, Social, and Governance) mandates as per SEBI (Securities and Exchange Board of India) rules. This review aims to offer valuable insights for policymakers, researchers, and practitioners in India and around the world who are dedicated to reducing carbon emissions and promoting sustainable development in the Indian context.

GCDI_23126
Innovation and Eco Design for Sustainability

Vignesh Kanna M
M.E - Engineering Design
PSG College of Technology
22md09@psgtech.ac.in

Udhayakumar E
M.E - Engineering Design
PSG College of Technology
22md34@psgtech.ac.in

Prabu T
Professor,
PSG College of Technology,
tpr.mech@psgtech.ac.in

ABSTRACT

Eco-design is an all-encompassing technique that focuses on developing goods and services while paying close attention to how they will affect the environment from the extraction of raw materials to their eventual disposal. Innovation, on the other hand, entails the development and application of original concepts and solutions. Together, these components make up the cornerstone of sustainable practices, forming how environmentally conscious product development will be done in the future in a connected world. Innovation, which is characterized by technology advances, inventive problem-solving, and innovative ideas, is essential for promoting sustainable practices in a variety of industries. A key component of reducing resource consumption, pollution, and waste generation is eco-design, which emphasizes the incorporation of environmental factors into product development. This paper deals with sustainable eco design that are classified into three categories namely biodegradable products, transportation and packages, and recycling and its contribution in reducing carbon footprints. This paper explores the pivotal intersection of innovation and eco-design as essential strategies for achieving sustainability in the modern era.

GCDI_23127
**A Review on Significance of the Circular Economy in Addressing Climate Change:
A Perspective Using the Theory of Change Methodology**

Sathesh Kumar S
ME engineering design,
PSG College of Technology
Email: 22md06@psgtech.ac.in

Dr Prabu T
Professor,
PSG college of technology
Email: tpr.mech@psgtech.ac.in

ABSTRACT

This study employs a theory of change framework to investigate the emerging relationship between the circular economy (CE) and climate change, drawing upon a multidisciplinary examination of Arts and Humanities, Business, Management and Accounting, Economics, Econometrics and Finance, and Social Sciences literature. The circular economy is introduced as a sustainable development strategy that centres on the 9R principles of refuse, reduce, rethink, repair, reusing, refurbish, remanufacture, repurpose, recycle and recovering materials, creating a circular system where materials are continually recycled, renewable energy is prioritized, activities support ecosystem regeneration, human health, and societal well-being, and resources are leveraged to generate value. This review provides an overview of CE's concept and current practices while evaluating its implementation and highlighting the urgency of shifting away from the linear economic model of material extraction, production, and waste disposal. It also introduces existing practices and discusses standards for assessing CE's development and performance, emphasizing key indicators.

GCDI_23128

Climatic Impact On Thermal Power Plant

Ravi Shankar R
M.E - Engineering Design,
PSG College of Technology
22md04@psgtech.ac.in

Dr Prabu T
Professor,
PSG college of technology
Email: tpr.mech@psgtech.ac.in

ABSTRACT

As the primary source of electricity on Earth, thermal power plants are essential to the generation of energy. However, given how vulnerable they are to climate change, these plants could face difficulties on both an operational and environmental level. An overview of the many climatic elements that have an impact on thermal power plants and their extensive effects is given in this abstract. The efficiency and dependability of thermal power plants can be greatly impacted by changes in temperature patterns brought on by climate change. Increasing ambient temperatures can result in decreased cooling effectiveness, an increase in the need for cooling water, and decreased turbine performance, all of which can have an impact on power generation output. In addition, extreme weather conditions like hurricanes, droughts, and flooding can affect power plant operations, harm infrastructure, and endanger workers' safety.

GCDI_23134

Grid To Vehicle and Vehicle To Grid Bidirectional AC-DC Converter and DC-DC Converter

Dr Archana Naganathan
Assistant Professor (Sl. Gr.),
Dept. of Electrical and Electronics Engineering,
PSG College of Technology, Coimbatore
naa.eee@psgtech.ac.in

Dr R Latha
Associate Professor,
Dept. of Electrical and Electronics Engineering,
PSG College of Technology, Coimbatore
rla.eee@psgtech.ac.in

Kaviya M
Dept. of Electrical and Electronics Engineering,
PSG College of Technology, Coimbatore
kaviyamp18@gmail.com

Nivetha D
Dept. of Electrical and Electronics Engineering,
PSG College of Technology, Coimbatore.
nivethadevaraj2204@gmail.com

ABSTRACT

Batteries produce electrical energy through a chemical process occurring inside the cell. Ideally, this occurs when the battery is connected to a device requiring power. However, the chemical reaction can also take place on a smaller scale when the battery's electrodes are not connected, resulting in a gradual reduction of the battery's charge over time. It is impossible to completely prevent this self-discharge of the battery. Consequently, the concept of vehicle-to-grid (V2G) arises. This involves storing the energy generated during periods of low demand and reintroducing it into the system when demand is high. Bidirectional converters are employed for charging the battery, enabling power transfer in both directions. To interface electric vehicles (EVs) with the system, a micro-grid test system is created. Simulation studies are conducted to showcase the transfer of power from V2G to grid-to-vehicle (G2V) applications.

GCDI_23135 Climatic Impact On Thermal Power Plant

S Babu
Associate Professor,
PSG College of Technology,
Coimbatore
sjsham@gmail.com

Govindaraj M,
Associate Professor,
K. Ramakrishnan College of
Technology,
Trichy.

Starvin M S,
Assistant Professor (Sr.Gr),
University College of Engineering,
Nagercoil.

Sivaprasad T V,
Chief Manager/C&I,
Planning dept, 2*500MW NNTPS,
NLC India Limited

Darwin Dayanandan S
ME Energy Engineering student,
PSG College of Technology,
Coimbatore

ABSTRACT

The scope of this paper is to analysis the boiler performance by using detailed energy audit method and discussed the identification of energy saving potential option, limitation of the boiler, effective utilisation of the thermal energy and energy conservation opportunities are covered. Initially undergo the energy auditing on 650TPH coal fire water tube boiler and evaluate the performance analysis. Initially this chapter briefly deals with the account of present efficiency level of coal fired boiler unit. There are two important parameters to evaluate the boiler performances analysis, there are, 1) boilers are efficiency calculation and 2) evaporation ratio. These values are totally depending upon the fuel quality, combustion, insulation, Draft control, cleaning, Scales & Sludges, Priming, Caustic embrittlement, Boiler corrosion, Foaming, Carryover, water quality, fouling of the tubes, operation and maintenance. Efficiency testing help us to understand the present efficiency level is how much deviate from the design efficiency level. Observed deviation could be identified and investigated in each components wises to take a necessary corrective action. Hence, the good selection of boiler is necessary that also depends on the working pressure, quality of steam required, Steam generation rate, available floor area, accessibility for repair and inspection, comparative initial cost, erection facilities, load factors, availability of fuel & water available, Operating and maintenance costs. The boiler system is the major one to analyse the thermal performance study in the energy conversion industry

GCDI_23136 Climate vulnerability and its impact on financial markets

D Susana
PSG Institute of Management,
PSG College of Technology,
Coimbatore, India
susana@psgim.ac.in

V Srividya
PSG Institute of Management,
PSG College of Technology,
Coimbatore, India
srividya@psgim.ac.in

R R Sathya
PSG Institute of Management,
PSG College of Technology,
Coimbatore, India
r.r.sathya2000@gmail.com

ABSTRACT

Climate changes in the environment are driven by various factors, including global warming and the emission of CO₂ from technological advancements and industrial activities. The adverse climate conditions, known as climate risks, have profound implications for people livelihoods, economies, ecosystems, and investments. Climate vulnerability measures the extent to which these risks impact communities in specific regions. Assessing a country's exposure, sensitivity, and ability to adapt, the climate vulnerability index helps gauge the nation's resilience to these risks. These climate risks not only threaten macroeconomic stability but also hinder a country's overall economic growth. Extreme weather events not only destabilize financial markets but also affect the financial performance of businesses, which are vital for a nation's progress. It is imperative to study the financial repercussions of these climate events and take necessary measures to mitigate their impact. In this context, this paper examines the research conducted on how climate vulnerability affected crucial financial indicators such as foreign exchange rates, foreign direct investments, and stock markets in different countries. A theoretical framework is proposed to explore the impact of climate vulnerability on these financial metrics across diverse nations.

GCDI_23137**Managing the Convergence: How Industry 4.0 can augment India's Decarbonization Vision**

Dr V Harish
Assistant Professor,
PSG Institute of Management,
harish@psgim.ac.in

ABSTRACT

This research paper provides a thorough analysis of the possible synergies between Industry 4.0 and India's decarbonization objective and It attempts to critically evaluate the use of technological advancements to support the country's economic transformation. This paper provides a all-inclusive analysis of the contemporary situation, challenges, and prospective benefits associated with the incorporation of Industry 4.0 technologies into India's decarbonization goals and presents strategic perspectives and suggestions for attaining a future that is both digitally advanced and environmentally conscious. The introductory sections of the paper provide a comprehensive overview and justification for the study, elaborating on the significance of the research, its primary objectives, and the extent of its contributions and the next section presents a comprehensive literature review in order to investigate the various nuances of I 4.0 and its applicability in India and also presents a comprehensive examination of the several technologies associated with Industry 4.0, as well as an analysis of their present acceptance and implementation patterns within the context of India as well as at the global context.

GCDI_23139**Air Gap Analysis and Optimization for 2.8MW Permanent Magnet Synchronous Generator**

Babu S
Associate Professor,
PSG College of Technology
babu.mech@psgtech.ac.in

Harish Babu V
BE Mechanical Engineering,
PSG College of Technology,
Coimbatore

Aasis Nishaar Taggala
BE Mechanical Engineering,
PSG College of Technology,
Coimbatore

R V Tharunishvar
BE Mechanical Engineering,
PSG College of Technology,
Coimbatore

Mr Saravanaprabhu
Plant Supervisor,
FABTEX Engineering works,
Coimbatore.

ABSTRACT

Wind turbines are devices that harness the kinetic energy from the wind and convert it into electrical power. They play a crucial role in the generation of renewable energy and have various applications across different sectors. Depending on the factors like wind conditions, available space, and specific application requirements, a spectrum of generator designs are in the market. One such design whose efficiency and reliability makes it suitable for capturing wind energy in diverse environmental conditions, is the Permanent Magnet Synchronous Generator (PMSG) Wind Turbine. More than a decade ago, manufacturers of Regenpowertech forayed India into the direct-drive design with their 1.5MW PMSG Wind Turbine. Due to it's self-excitation property, PMSG's are more efficient than induction generators. With minimal maintenance requirements and optimal energy conversion, PMSGs stand out as a robust and reliable choice for harnessing wind power. Even with such robust machines, there have been instances of failure: during abnormal wind loading, fluctuations in the system, etc., Unsteady wind speed causes vibration in the system and puts a stiff on the performance of the wind turbine. Such condition led to the damage of various elements of the generator, including the rare earth metal-made PMs. The extent of damage is studied by taking sample specimen from the wind turbine. A detailed analysis is needed to perceive into the root cause of failure and solutions to eliminate the cause of failure. Wide scale testing and simulations allow to collect data points on the performance of the generator under varying conditions. Several researchers studied the performance of the PMSG wind turbine experimentally and enhanced it over the years. The air-gap between the stator-rotor is under focus, and design optimization is required to eliminate the cause of failure while upholding the level of performance of the PMSG wind turbine.

GCDI_23140**GIS - Based Impact Studies on The Proposed Metro Rail corridor -
Coimbatore city and Local Planning Area (LPA)**

Thilagam A
Department of Civil Engineering,
PSG College of Technology,
Coimbatore, India
atp.civil@psgtech.ac.in

Pushpa S
Department of Civil Engineering,
PSG College of Technology,
Coimbatore, India

ABSTRACT

Metro rails had been introduced, to overcome increasing levels of traffic congestion. Planners have realized the need for the metro rail in Coimbatore city. The implementation of metro rail in Coimbatore city will have some impacts. Site suitability of metro stations is done by weighted overlay analysis based on the five criteria. The weightage given for the criteria is based on the Analytical Hierarchy Process (AHP). The impact on urban development is studied by comparing land use patterns between 2011 and 2019 and a buffer zone of 1 km is considered for the selected station. The stations in the proposed corridors are classified into inner periphery stations and outer periphery stations considering the city boundary limit. Construction of Metro stations in inner periphery corridors decongests the roads. In outer periphery corridors, there is scope for future urban development.

GCDI_23141**Syntropic Agroforestry: A Sustainable Solution for Carbon Emission Reduction in India**

Dr Asha Nair
Assistant Professor,
PSG Institute of Management,
Coimbatore
asha@psgim.ac.in

Dr Prabhu Thangadurai
Assistant Professor

Dr N Vivek
Professor,
PSG Institute of Management,
vivek@psgim.ac.in

ABSTRACT

Addressing global concerns over escalating carbon dioxide (CO₂) emissions and their impact on climate change, this paper scrutinizes the potential of syntropic agroforestry as a sustainable avenue for carbon reduction in India. Focusing on the shortcomings of traditional reforestation methods and their limited revenue generation, this research advocates for syntropic agroforestry as a viable alternative. Synthesizing data from credible sources and emphasizing the innovative nature of syntropic agroforestry, the study underscores its capability to sequester carbon while offering substantial economic benefits. It delves into the intricacies of implementing and assessing syntropic agroforestry systems, emphasizing their capacity for carbon removal and water retention. Furthermore, this paper bridges theory and practice, proposing policy implications to support the adoption of this eco-friendly agricultural practice, thereby fostering environmental preservation and sustainable economic growth.

GCDI_23142

**A study on power generation carbon footprint change in the state of
Tamilnadu using solar PV and PVT technologies**

V V Divya

Assistant Professor,

Department of Mathematics With Computer Applications,
PSG College of Arts & Science, Coimbatore - 641004.
divyavicky@gmail.com

S Babu

Associate Professor,

Department of Mechanical Engineering,
PSG College of Technology, Coimbatore - 641014.
babu.mech@psgtech.

M Naveenya

Student,

Department of Mathematics With Computer Applications,
PSG College of Arts & Science,
naveenyanaveenya065@gmail.com

ABSTRACT

The greenest of energy sources is solar energy. There are many approaches to harnessing solar energy. Two of the most popular ones are solar photovoltaic and solar thermal energy. Electricity power generation is one of the largest generators of CO₂ on the planet. So, any effort to use alternate methods will directly affect the carbon footprint of the generating station. Although producing the solar generators does have a carbon emission attached to it, in the long run, this is offset by a cleaner power generation method. The solar photovoltaic cells work on the photo electric effect and convert solar light into electricity directly. Here the heat generated on the solar panels is dissipated using a coolant but not used for any productive purpose. Customers typically use the majority of the energy for heating. Therefore, solar thermal solutions were also necessary. Consequently, a generator that produces both electricity and heat using the same apparatus was developed and given the name solar photo voltaic thermal solutions. This generator makes two uses of the solar energy that is directed towards earth. This research aims at computing the impact of replacing 30% of power generation in Tamilnadu state by solar PV and solar PVT generators. The financial implications and the CO₂ offset have been generated. This is meant to serve as a guide for policy making by the appropriate governing authorities in the state. The power and energy consumed by the major cities in Tamilnadu state have been collected. This is then used to decide the target power production to be achieved using solar technologies. This number is fixed using a 30% target level for the power required. This is then compared to the generating capacities of solar PV and solar PVT technologies to arrive at the total area required for the research, the cost of the research and the CO₂ emission cuts to be achieved. The standard data available with the government departments has been used for the energy requirement calculations. The solar PV and solar PVT panel costs, power generating capabilities and CO₂ reduction are collected from published sources and industry suppliers. This is used to compute the investment required in the state to achieve the targeted emission cut.

GCDI_23144**A roadmap for India towards decarbonization**

Dhinesh Ram R

Department of mechanical Engineering
PSG College of Technology, Coimbatore
22md01@psgtech.ac.in

Rampasath R

Department of mechanical Engineering
PSG College of Technology, Coimbatore
22md32@psgtech.ac.in

Dr Prabu T

Professor, Department of mechanical
Engineering, PSG College of
Technology, Coimbatore
tpr.mech@psgtech.ac.in

ABSTRACT

In India, there is the will to move away from fossil fuels as much and as early as possible. greenhouse gas emissions have become central to any discussion on energy system choices. Technological progress has brought to the fore a growing number of technologies that can be adopted at a commercial scale. Furthermore, there is urgent need to eliminate the dependence on fossil fuels. We are pitching for energy transition in international forums and displaying that intent in our domestic policies. India has aimed high, decarbonizing 50% of its energy by 2030. Innovative policies to avoid dependency on fossil fuels and ensure long-term sustainability are required. In addition to this, investment in R&D has to be scaled up. Domestic manufacturing also needs appropriate incentives to become Aatma Nirbhar Bharat. Energy is at the heart of economic development and perhaps no country is more challenged than India as it strives to create a better life for its population of almost 1.4 billion people. The Discussion Paper makes a constructive contribution to the public debate on the range of issues, which need to be addressed for the achievement of the highly ambitious 2030 goals set by the Prime Minister. We look forward to engaging closely with multiple stakeholders in the coming years and working towards achieving India's energy ambitions that require an unprecedented scale of transformation along a pathway never followed by other countries of rapidly increasing energy consumption and decarbonizing energy at the same time. The electricity sector in India has undergone rapid transformation in recent decades. The country has successfully electrified all households. There is adequate power generating capacity whose optimal utilization is facilitated by an integrated national grid. Reliable, affordable, quality, round-the-clock power supply to all is the goal to be achieved in the next few years. India is now committed to the energy transition of decarbonization and achieving a state of net zero emission. India has made remarkable progress in recent years. It now has the 5th largest solar and 4th largest wind power capacity in the world, with their total capacity being over 100 GW. Though the share of renewables in total electricity generation is now over 10%, more than 70% of the country's electricity was still generated by fossil fuels in 2021.1 At COP26, India announced the highly ambitious goal of decarbonizing energy to 50% and achieving 500 GW of fossil fuel free generating capacity by 2030.

GCDI_23146**Advances in Waste to the Energy System for Decarbonisation in Coimbatore**

M Shiva guru

M.E-Engineering Design
PSG college of technology
22md33@psgtech.ac.in

Dr Prabu T

Professor- Mechanical Engineering
PSG college of technology
tpr.mech@psgtech.ac.in

ABSTRACT

Urbanization has led to increased challenges in waste management, posing health risks and contaminating soil, water, and air. A project in Chennai, Tamil Nadu, Asia, proposed a sustainable and integrated garbage model called the "Decentralized model" to handle trash close to the point of origin, avoiding large-scale land filling and transportation. Coimbatore, a developing smart city, faces environmental neglect in waste management. A coordinated system of waste generation and disposal control is necessary for effective techniques. Most waste management methods, such as landfills, have positive environmental effects, but incineration and sanitary landfills have drawbacks like large-scale greenhouse gas emissions. A study was conducted to determine the flow of cell phones that will soon be considered e-waste. Municipal solid wastes in Coimbatore are a combination of organic and inorganic waste, with residents heavily relying on plastics. Proper disposal of mountainous wastes should use sanitary landfills, paralysis, and incineration instead of regular landfills. The organic portion of municipal solid waste can be composted to create a soil fertility medium.

GCDI_23147
Offshore Wind Generators

Dr M Shyamalagowri
Associate Professor / EEE,
Erode Sengunthar Engineering College,
Perundurai, Erode –638057
mshyamalagowri2011@gmail.com

ABSTRACT

Offshore wind generators, a pivotal component of the renewable energy landscape, utilize advanced wind turbine technology in marine environments to generate clean and sustainable electricity. Positioned in oceans, seas, or large lakes, these turbines are designed for the unique challenges of offshore conditions. They feature robust foundations that can withstand powerful waves and currents, while their massive rotor blades capture the consistent and strong offshore winds. Electricity generated is transmitted to the mainland via undersea cables, integrating into the grid to power homes and industries. Offshore wind farms offer several advantages, including higher wind speeds, minimal visual impact, and potential for greater capacity. While they play a crucial role in reducing carbon emissions and promoting sustainable energy, they also face challenges like high installation costs and environmental considerations. Offshore wind energy represents a promising frontier in the pursuit of cleaner and more abundant power sources. Offshore wind generators represent a cutting-edge and rapidly expanding sector in the renewable energy landscape, offering a promising solution to the world's growing energy needs while combating climate change. These advanced turbines are strategically positioned in the open waters of oceans and seas to harness the power of strong and consistent offshore winds. Offshore wind farms are characterized by their towering turbines with massive rotor blades, designed to withstand the demanding marine environment. This technology boasts several advantages over onshore wind, including higher wind speeds and reduced visual impact, making it an attractive option for sustainable energy production. The electricity generated by offshore wind generators is transmitted to the mainland through undersea cables, contributing to the grid and powering homes and industries. Despite the significant potential for clean energy generation, offshore wind farms face challenges, including higher installation and maintenance costs, environmental concerns, and the necessity for specialized infrastructure. Nevertheless, they hold great promise in the global transition to cleaner and more sustainable energy sources, and their expansion is critical in mitigating the impacts of climate change while meeting growing energy demands.

GCDI_23148
Modification of Small Wind Turbine Airfoil for Sustainable Power Generation

Naveen Jayakumar A
Student
PSG college of technology
20M622@psgtech.ac.in

Dr Prabu T
Professor- Mechanical Engineering
PSG college of technology
tpr.mech@psgtech.ac.in

ABSTRACT

Demonstrating the role that wind energy plays in the renewable energy environment and the application of CFD simulations to improve air foil lift coefficients. Using verified CFD models for the selected air foil, the investigation starts by determining a baseline lift coefficient. Later studies examine changes to the geometry of the air foil and other design specs. The research also explores the hybridization of air foils, assessing the combined impacts of various air foil sections to determine an optimal aerodynamic performance. This study finds particular design changes that significantly affect the lift coefficient of the air foil through systematic simulations and computer analysis. The overall lift coefficient is significantly increased by using the hybridization process. It has also been shown that adding serrations to the bottom surface of the air foil increases pressure and, consequently, the lift coefficient. By superimposing the serrations onto the hybridized air foil, the study extends this finding and increases the overall lift coefficient even further. An important step forward in the search for aerodynamic efficiency is suggested by the research, which builds on these findings and suggests switching to a bionic-shaped air foil to attain a maximum optimal lift coefficient. As a means of enhancing the lift coefficient of air foils, the study's results offer insightful information on possible enhancements that can be achieved by means of geometric modifications, hybridization strategies, and the incorporation of bionic-inspired design. The results reveal that the lift coefficient may be increased significantly, indicating the possible improvements that can be made by modifying the geometry of the air foil and using different hybridization techniques. By offering valuable insights into efficient air foil design improvements that result in increased efficiency and lift performance.

GCDI_23149
IOT based Waste Management System for Smart City

R Sureshkumar
Assistant Professor,
RAE Department,
PSG College of Technology, Coimbatore
rsk.rae@psgtech.ac.in

ABSTRACT

The Collection of waste is very essential in municipal service that requires huge expenditures and execution of this operation is high-priced. The high cost is caused by a number of variables, including labour, fuel, maintenance, and environmental expenditures. For proper waste management, the aforementioned reason makes the design, development, and execution of the intelligent smart bin necessary. The implementation of an embedded IoT system with a WIFI module, sensors, microcontroller, and GPS for monitoring trucks and garbage bins in real-time environments was the main focus of this research. Web-based Android applications were created to communicate with a web server and inform the municipality of the workers' cleaning efforts. To track and effectively manage garbage collection techniques, this system offers a database of information about bin condition, amount of waste in the bin, and time of waste pickup. In order to lower the cost, graph theory optimization algorithms evaluated this data to determine the shortest path to the bin. There are numerous types of waste that need to be gathered. The priority-based database is created by the controller on the server. The truck will receive the signals from the server to collect the trash. The truck then collects the rubbish in a certain Zone according to the priority.

GCDI_23151
Evaluation of Energy Conservation Opportunities in Gloves Industry

Muthukannan Marimuthu
mmk.mech59@gmail.com

ABSTRACT

The objective of this article is to share the experience of energy saving potential carried out by the rubber gloves industries. Gloves manufacturing industries is an energy intensive industry also. It absorbs both electrical and thermal energy in substantial also. On an average, the monthly energy consumption was about 48 320 kWh and the corresponding fuel wood consumption was 320 tons / month. It is discernible that economic and efficient measures of energy conservation have been observed in the present paper. The present detailed audit provides a deep insight into the thermal energy generation consequential aspects of utilization/distribution in the process. The energy conservation schemes are identified and proposed in the present paper - when implemented- are expected to bring in lasting benefits (savings) in terms of energy as well as cost to the management. After the data was finalized, Energy Conservation Measures (ECMs) were identified and subsequently evaluated on technical and economical basis. Brainstorming was also carried out with key plant personnel to arrive at realistic evaluations of ECMs. Energy savings methods and payback period were also presented in detailed format. The energy saving methods like done by using the different methods like surrendering 50KVa, use of energy efficient motors, use of synthesis energy efficient flogged V-Belt drives and storage of firewood in closed shed to avoid moisture absorption of wood. The annual energy savings is detected around 16,02,895 and payback period is maximum around 26 months.

GCDI_23152**Rethinking Network Distribution Charges Design in the context of increasing active consumers in the Indian Electricity Market**

Arun Karthik B
PSGIM, Coimbatore
arunkarthik@psgim.ac.in

ABSTRACT

The International Renewable Energy Agency (IRENA) estimates that 90 percent of the world's electricity can and should come from renewable energy by 2050. Moving to renewable energy generation is accepted as a solution by governments all over the world to tackle greenhouse gas emissions. The production of renewable energy is encouraged by governments at mass scales by electricity generation companies and at small scale by consumers of electricity. So, the production of electricity, from being centralized, is increasingly becoming distributed. Even-though active consumers draw less electricity during day time from the grid because they produce electricity from solar, they depend on grid for times when solar electricity is not available. Electricity networks attain their maximum load at times when solar electricity generation is not available. Capacity for electricity generation systems and for transmission systems are designed for peak loads. Construction and installation of electricity generation and transmission systems involve high proportion of fixed costs. The electricity charges paid by the consumer comprises of variable costs and part of fixed costs for electricity generation and transmission system. Continuous decrease in off-peak load capacity utilization without commensurate decrease in peak load capacity utilization leads to commensurate decrease in the total electricity produced by conventional electricity generation systems. Since the fixed costs incurred for electricity generation systems has to be recovered by appropriately charging the electricity generated by the generation system, with decrease in total number of units generated, the fixed cost component in the electricity charges keeps increasing proportionately. Changes in electricity generation mix have lead to the necessity of redesigning distribution network in such a way that the efficient network usage is promoted and consumers are charged based on their access to the electricity generation capacity. This study is an attempt to find the impact of solar electricity adoption on capacity utilization in conventional electricity generation systems and the impact of solar electricity adoption and network charges on the financial health of Distribution Service Operators.

GCDI_23154**Design and Analysis of a Proposed Energy Harvester for Turbine Vent Using Piezoelectric and Tribo- Electric Nano-Generators**

Sathesh Kumar S
ME engineering design,
PSG College of Technology
22md06@psgtech.ac.in

S. Udhayakumar
Assistant Professor,
PSG college of technology
suk.mech@psgtech.ac.in

ABSTRACT

The development of sustainable energy harvesting technology is being propelled by the growing global need for energy and environmental concerns. Although wind energy is a renewable energy source that is abundant, conventional wind turbines are only effective at capturing wind energy at high wind speeds. In order to produce electricity from low-velocity wind, a novel wind energy harvesting system combining piezoelectric materials and triboelectric nanogenerators (TENGs) is proposed in this study. When two triboelectric materials come into touch and separate, TENGs have the ability to produce electricity. When mechanical stress is applied to piezoelectric materials, electricity can be produced. The suggested devices are used in energy harvester system and incorporated in a turbine vent fan to gather wind energy at low wind velocities. The proposed energy harvester system will generate electricity at wind velocities as low as 3 m/s. This system has the potential to power small electronic devices and sensor networks without replacing the batteries

GCDI_23155

Analyzing Two Wheeler Aftermarket Parts Based on Perspective of Two Wheeler Technicians

Pavan P
Student

Department of Mechanical Engineering,
PSG Itech, Coimbatore.
21m135@psgitech.ac.in

Susikaran R
Student

Department of Mechanical Engineering,
PSG Itech, Coimbatore.
21m154@psgitech.ac.in

Mr T Prem Kumar
Assistant Professor

Department of Mechanical Engineering,
PSG Itech, Coimbatore.
premkumar@psgitech.ac.in

Dr S Babu Sham
Associate Professor

Department of Mechanical Engineering,
PSG Itech, Coimbatore.
babu.mech@psgitech.ac.in

ABSTRACT

The study aimed to understand and identify the fast-moving aftermarket parts from the perspective of two-wheeler technicians and to analyse the key characteristics of the same. In this survey 100 two-wheeler technicians were interviewed, 24 areas in Coimbatore were covered, 46 individual parts were recorded and highly demanded parts were identified. Their key characteristics like expected part life, reason for failure, brand recommended by the technician and the reason for recommending the brand were analysed. Descriptive survey research methodology was implemented. The average experience of an individual technician was 21.8 years. Spark plug, Sprocket bearing, Rollers, Fork oil seal Engine oil, Electrical parts, Chain sprocket, Brake shoe, Carburetor, Air filter, Fork oil, Clutch, Cables and Brake oil were the parts that were further analysed. The main reason for the recommendation of the brand was quality over budget. Air filter, Engine oil, Chain sprocket, brake show were most demanded and serviced parts during the servicing of two wheelers as per the technicians.

Impact of Quantum Locking in Sustainable Manufacturing Practices

Dinesh Krishnaa S
M.E Computer Integrated
Manufacturing

Department of Mechanical Engineering,
PSG College of Technology,
Coimbatore, India

J.Nashreen

IV year Production Engineering (sw)
Department of Production Engineering,
PSG College of Technology,
Coimbatore, India
nashreennas24@gmail.com

Syath Abuthakeer S
Associate Professor

Department of Mechanical Engineering,
PSG College of Technology,
Coimbatore, India
ssa.mech@psgitech.ac.in

ABSTRACT

In the realm of precision engineering and manufacturing, quantum locking emerges as a groundbreaking technology with the potential to revolutionize established practices. This comprehensive exploration delves into the intricate world of quantum locking, offering insights into its fundamental principles, mechanisms, and practical applications. Beginning with a quantum mechanics primer, delving into the quantum phenomena of superposition, entanglement, and quantum tunneling that underpin quantum locking. Then examine how quantum locking compares to traditional machining techniques, revealing its advantages in terms of precision, efficiency, and material utilization. Furthermore, exploring how quantum locking aligns with the principles of Industry 4.0, emphasizing its role in automation, connectivity, data-driven decision-making, and its integration into smart manufacturing systems. As of to conclude this journey, the promise of quantum locking as a catalyst for precision engineering's future becomes evident, offering a glimpse into a world where quantum phenomena redefine the boundaries of manufacturing excellence and innovation.

The First...
still the best...



OUR PRODUCTS

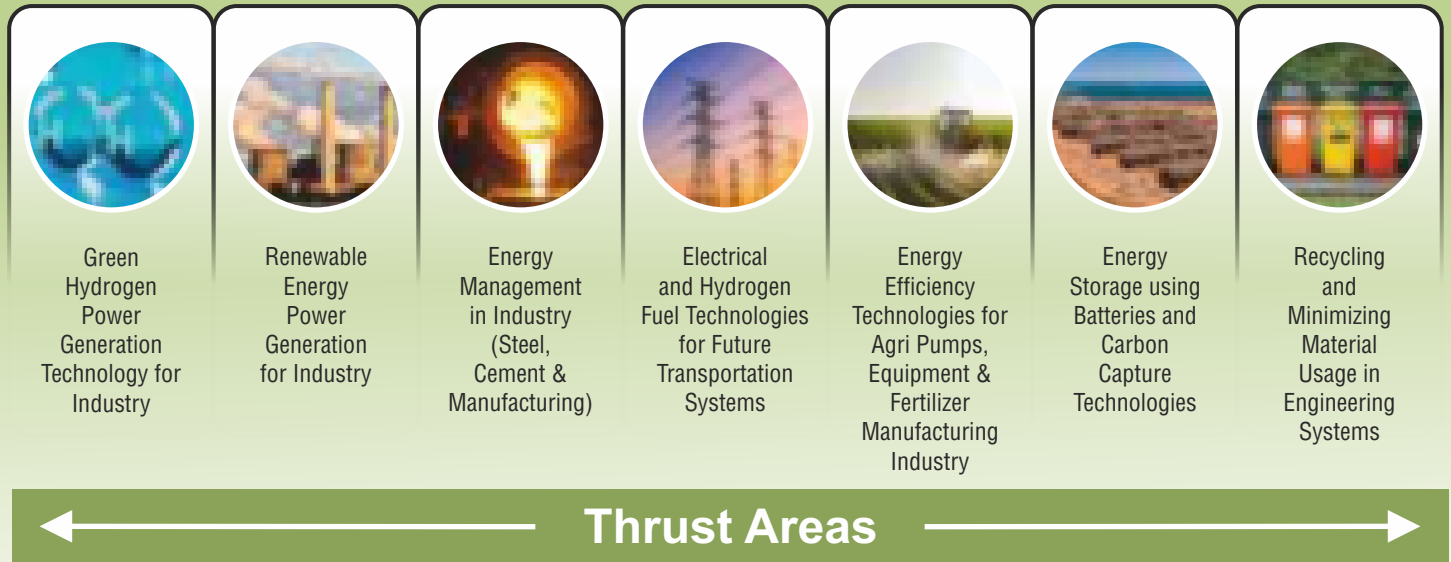
Agriculture Pumpsets | Aquaculture Pumpsets
Domestic Pumpsets | Solar Products
Electric Motor Sets | Control Panel Boards
Compressors | Flat Cables

PSG INDUSTRIAL INSTITUTE

Coimbatore - 641 004.
Customer Care : +91 95 00 66 5553.
www.psgpump.org

PSG Institutions

1924	-	PSG SARVAJANA HIGHER SECONDARY SCHOOL
1926	-	PSG INDUSTRIAL INSTITUTE
1939	-	PSG POLYTECHNIC COLLEGE
1941	-	PSG MIDDLE SCHOOL, VEDAPATTI
1943	-	PSG PRIMARY SCHOOL, PEELAMEDU
1947	-	PSG COLLEGE OF ARTS AND SCIENCES
1951	-	PSG COLLEGE OF TECHNOLOGY
1961	-	PSG RURAL HEALTH CENTRE, VEDAPATTI
1974	-	PSG & SONS' CHARITIES METALLURGY AND FOUNDRY DIVISION
1985	-	PSG INSTITUTE OF MEDICAL SCIENCES AND RESEARCH
1985	-	PSG RURAL HEALTH CENTRE, NEELAMBUR
1986	-	PSG INDUSTRIAL TRAINING CENTRE
1989	-	PSG HOSPITALS
1989	-	PSG CENTRE FOR SPONSORED RESEARCH AND CONSULTANCY
1989	-	PSG CENTRE FOR NON-FORMAL AND CONTINUING EDUCATION
1993	-	PSG URBAN HEALTH CENTRE
1994	-	PSG INSTITUTE OF MANAGEMENT
1994	-	PSG COLLEGE OF NURSING
1998	-	PSG RURAL HEALTH CENTRE, VELLALORE
1998	-	PSG SCIENCE AND TECHNOLOGY ENTREPRENEURIAL PARK (STEP)
1998	-	PSG TIFAC CORE IN PRODUCT DESIGN
1999	-	PSG COLLEGE OF PHYSIOTHERAPY
2001	-	PSG COLLEGE OF PHARMACY
2001	-	PSG CENTRE FOR ADVERTISING AND COMMUNICATION
2002	-	PSG CHILDREN'S SCHOOL
2003	-	PSG OFFSHORE HEALTH CARE MANAGEMENT SERVICES
2004	-	PSG RURAL HEALTH CENTRES, KARADIVAVI
2005	-	PSG HIGH SCHOOL, VEDAPATTI
2006	-	PSG INSTITUTE OF ADVANCED STUDIES
2008	-	PSG PUBLIC SCHOOLS
2012	-	PSG DRIVING SCHOOL
2013	-	PSG VISHNUGRANTHI
2014	-	PSG INSTITUTE OF TECHNOLOGY AND APPLIED RESEARCH, NEELAMBUR
2015	-	PSG CENTRE FOR ACADEMIC RESEARCH AND EXCELLENCE
2017	-	PSG SOFTWARE TECHNOLOGIES
2021	-	PSG INSTITUTE OF ARCHITECTURE AND PLANNING



About the Conference

India is emitting 2.9 GtCO₂e (4.9% of global emissions) annually as the third largest emitter with 1.8 tons CO₂e per capita emission. As the Indian economy is growing, it has to carefully plan and execute its economic growth while achieving its decarbonizing goals. Power, automotive, aviation, steel, cement and agriculture are the major sectors contributing to around 70% of India's overall emissions. It is to be expected that India could get to its net-zero-by-2070 commitment through technology developments over the next decades. As per the recent (2022) McKinsey report, over three-fourths of the industry in the India of 2050 (and 80+ percent of the India of 2070) are yet to be built. If policies are set in place to create the right demand signals within this decade, then the capacities India adds in the two decades thereafter will be low carbon ones. India may need an estimated US\$7.2 trillion of green investments until 2050 to decarbonize.

Organized by



Department of Mechanical Engineering
PSG College of Technology

Co-Organizers :



AICE

Australia India Centre for Energy



CENTER FOR ACADEMIC RESEARCH & EXCELLENCE