CAETS ENERGY COMMITTEE PROJECT

TRANSITIONING TO LOWER CARBON ECONOMY

Technology and Engineering Considerations in Building and Transportation Sectors

Edited by:

Dr. K V Raghavan, FNAE & Dr. Baldev Raj, FNAE

A Report for

The International Council of Academies of Engineering and Technological Sciences (CAETS)

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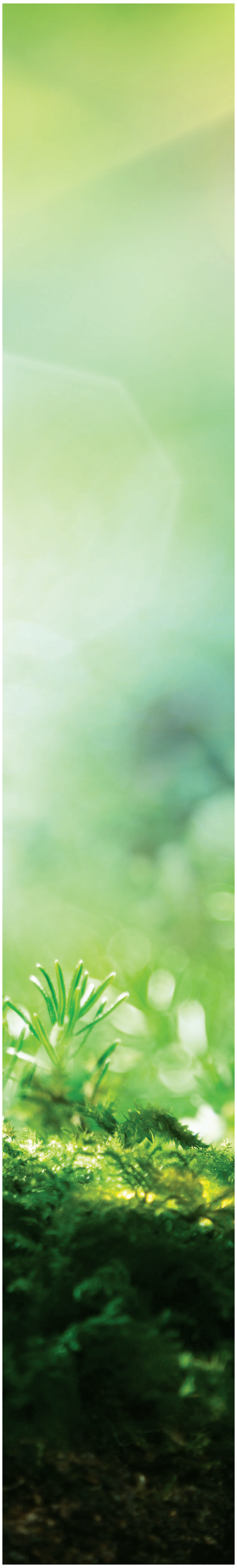

Acknowledgements

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Preface

In 2009, the International Council of Academies of Engineering and Technological Sciences [CAETS] approved studies on the technological and engineering issues related to transitioning to lower carbon energy in the building and transportation sectors, which together account for more than 50% of the global energy and GHG emissions. Lot of complexities arise in adopting lower carbon energy technologies mainly since the existing fossil fuel infrastructure is well established; less upfront investments are required for their expansion and the attractiveness of their retail cost structure on short-term basis. The CAETS Energy Committee, under the Chairmanship of Dr. Baldev Raj, FNAE, agreed to undertake this activity under the theme “Transitioning to a Lower Carbon Economy: Technological and Engineering Considerations for Building and Transportation Sectors“. The Indian National Academy of Engineering [INAE] was given the responsibility of coordinating the report preparation with Dr. K V Raghavan, FNAE as the Coordinator. An INAE Drafting Bommittee was formed to assist the CAETS Energy Committee in preparing the report.

The CAETS Energy Committee met at Cape Town, South Africa [November 2013], Beijing, China [June 2014], Berlin, Germany [November 2014] and London, UK [May 2015] to finalise the contents, subject coverage, intermediate reviews, mid-course corrections and outcome of the report. Brainstorming discussions were held to resolve several issues in grey knowledge areas. The London meeting gave the green signal to the formal release of the electronic version of the above report on 13 October 2015 at the inaugural function of CAETS Convocation – 2015 at New Delhi in India. The INAE drafting team had prepared five drafts of the report for review and modifications by the subject experts specially identified by the CAETS Energy Committee from time to time. The report contains four chapters reviewing the energy and GHG emission scenarios, energy-efficient engineering equipment options, case studies of world’s best examples of low emission systems and technological and engineering considerations for transitioning to lower carbon energy in the building and transportation sectors. The CAETS Energy Committee had made a special review of technologies related to high impact making energy-efficient building and transportation systems. The overall findings of the wide-ranging reviews are presented in Chapter 4 of the report for the benefit of policy makers, executive engineers and the other concerned stakeholders. This report is one of the most comprehensive documents on technological and engineering options for achieving energy-efficient building and transportation systems, which are essential for transitioning into a lower carbon economy.

On behalf of INAE Drafting Committee and on our own behalf, we would like to express our deep sense of gratitude to the members of the CAETS Energy Committee for their outstanding knowledge inputs, guidance and thoughtful interventions while compiling this report. We are particularly grateful to Prof Philip Lloyd of South African Academy of Engineering [SAAE], Dr. Zhou Ji of Chinese Academy of Engineering [CAE], Prof Frank Behrendt of German Academy of Engineering [ACATECH] and Dr. John Loughhead of Royal Academy of Engineering, UK [RAE]. They had made excellent arrangements and hospitality extended to the CAETS Energy Committee members during their meetings at Cape Town, Beijing, Berlin and London respectively. Special thanks are due to the subject experts for their valuable engineering inputs. There were informal consultations on energy-efficient building envelopes and road transport vehicles with eminent experts attending the Second International Conference on Sustainable Urbanization held in Hong Kong during 7-9 January 2015. Thanks are due to them.

The INAE Drafting Committee received strong support from the immediate past and current Presidents of INAE. Our gratitude goes to them. Brig Rajan Minocha, Dr. Geetanjali and other colleagues from INAE provided invaluable support at all stages of this assignment. We express our sincere thanks to them. Finally, we would like to express our appreciation of the unqualified support extended to us by Dr. B Chandrasekharam and Dr. BM Reddy of the CSIR-IICT as members of INAE Drafting Committee. We are sure, this report, with its unique subject coverage, will make high impact on the fellowship of CAETS member academies and its International readership.

Dr. K V Raghavan
Editor and Coordinator
INAE Drafting Committee

Dr. Baldev Raj
Editor and Chairman,
CAETS Energy Committee

Glossary of Terms

ACATECH	German Academy of Science and Engineering,
AEMS	Advanced Energy Management Systems
ASHP	Air Source Heat Pumps
ASHRAE	American Society of Heating, Refrigeration and Airconditioning Engineers
ATSE	Australian Academy of Technological Sciences and Engineering
BAU	Business As Usual
BEV	Battery Electric Vehicle
BTL	Biomass to Liquid Fuels
CAE	The Canadian Academy of Engineering, Canada The Chinese Academy of Engineering, China
CAETS	The Council of Academies of Engineering and Technological Sciences, NY
CAFE	Corporate Average Fuel Economy, USA
CAGR	Compound Annual Growth Rate
CBD	Commercial Buildings Disclosure Regulations of Australia
CCS	Carbon Capture and Sequestration
CFD	Computational Fluid Dynamics
CH/C	Composite Heating/Cooling
CHP	Combined Heat and Power Systems
CIT	The International Rail Transport Committee, Berne, Switzerland
CPA	Centrally Planned Asia
CREST	Centre for Renewable Energy and Sustainable Technologies
CTL	Coal to Liquids Fuels
CVT	Continuously Variable Transmission
EEU	Eastern Europe
EIP	Energy Improvement Potential
EMMA	Energy Monitoring and Management Tool
EPBD	Energy Performance of Buildings Directive
ETS	Emission Trading System
EU	European Union, Brussels, Belgium
EV	Electric Vehicle
FIA	Federation of International Automobiles, Paris, France
FSU	Former Soviet Union
GBAS	Green Building Assessment (China)
GFEI	The Global Fuel Economy Initiative
GHG	Green House Gases
Gt CO_2e	Giga tonnes of CO_2 emissions
GTL	Gas to Liquid Fuels
HCCI	Homogeneous Charge Compression Ignition
HDC	Heavy Duty Vehicles
HEV	Hybrid Electric Vehicle
HST	High Speed Train
HVAC	Heating, Ventilation, Air-conditioning and Cooling
IATA	International Air Transport Association, Montreal, Canada
ICAO	International Civil Aviation Organisation, Montreal, Canada
ICC	International Code Council, New Jersey, USA
ICE	Internal Combustion Engine
ICCA	International Council of Chemical Associations, The Netherlands
ICCT	International Council on Clean Transportation, Washington, USA
IEA	International Energy Agency, Paris, France
IECC	International Energy Conservation Code
IEEJ	The Institute of Energy Economics of Japan, Tokyo
IGCC	Integrated Gas Combined Cycle
IMO	International Maritime Organisation, London, UK
INAE	Indian National Academy of Engineering, India
IPCC	Intergovernmental Panel on Climate Change, Geneva
ISES	International Solar Energy Society, Freiburg, Germany
ITF	International Transport Forum, Paris, France
KGBCC	Korean Green Building Certification Criteria
LCA	Life Cycle Analysis
LCE	Lower Carbon Economy
LDV	Light Duty Vehicles
LEED	Leadership in Energy and Environmental Design (Canada, USA, India, Mexico and Others)
MDV	Medium Duty Vehicles
MEMS	Micro Electro Mechanical Systems
MFS	Ministry for state Security, German Democratic Republic
MINERGIE	Mehr Lebensqualitat, tiefer Energieverbrauch (Switzerland); Building Standards
MNA	Middle East and North
MOVES	Motor Vehicle Emissions Simulator (US-EPA)
MR	Modern Renewables
Mtoe	Million tonnes of oil equivalent
MWh	Megawatt Hours
NABERS	National Australian Built Environment Rating System
NAE	National Academy of Engineering, USA
NAEK	The National Academy of Engineering, Korea
NAM	North America
NLF/HLF	Natural/Hybrid Laminar Flow
NPEB	Net Positive Energy Building
NST	Normal Speed Train
NZEB	Net Zero Energy Buildings
OECD	Organisation for Economic Cooperation and Development, Paris, France
OTIF	Intergovernmental Organisation for International Carriage by Rail, Berne, Switzerland
PAS	Asia Pacific
PCM	Phase Change Materials
PEB	Passive Energy Buildings
PHEV	Plug in Electric Vehicle
POECD	Pacific OECD
RAEng	Royal Academy of Engineering, UK
RD&D	Research Development and Demonstration
RD	Rapid Deployment
RFG	Refrigeration
SAAE	South African Academy of Engineering, South Africa
SAFUG	Sustainable Aviation Fuel Users Group, Washington, USA
SATW	Swiss Academy of Engineering, Switzerland
SAS	South Asia
SBCI	The Sustainable Building and Climate Initiative, UNEP
SCCC	Super Critical Coal Combustion
SH/C	Space Heating/Cooling
SSA	Sub Saharan Africa
UNCTAD	United Nations Conference on Trade and Development, Geneva, Switzerland
UNEP	United Nations Environment Programme. Nairobi, Kenya
UNECE	United Nations Economic Commissions for Europe, Geneva, Swizerland
UNFCCC	United Nations Framework Convention on Climate Change, Rio
USCC	Ultra Super Critical Coal
USDOE	US Department of Energy, USA
WBSCD	World Business Council for Sustainable Development, Geneva, Switzerland
WEC	World Energy Council, London, UK
WEF	World Economic Forum, Davos, Switzerland
WEU	Western Europe
WH	Water Heating
WMO	World Meteorological Organisation
WWW	World Wide Web

General Conversion Factors for Energy

To/FROM	TJ	GCal	Mtoe	MBTu	GWh
TJ	1	238.8	2.388x10-5	947.8	0.2778
GCal	4.1868x10-3	1	10-7	3.968	1.163x10-3
Mtoe	4.1868x104	107	1	3.968x107	11,630
M BTu	1.0551x10-3	0.252	2.52x10-8	1	2.931x10-4
GWh	3.6	860	8.6x10-5	3412	1

CONTENTS

Executive Summary

By the end of the 21st century, the global average temperature could increase by 6°C as compared to the pre-industrial era, if the emission of carbon dioxide and other greenhouse gases remains unchecked. This could have large-scale humanitarian, environmental, political and economic consequences. The building and transport sectors together account for 50 % global energy consumption and 60+% GHG emissions. Their transition to lower carbon economy is extremely vital to contain global climate change. The transition process provides a dynamic period of technological change, innovation, experience sharing of alternatives, empowerment and entrepreneurship. National endeavours have to respond appropriately to climate change ahead of time, with technological options suitable to their local situations. This report can help fellowship of CAETS member academies to formulate interfaces with their national governments, policy makers, technology leaders and the concerned societies.

The CAETS Energy Committee has noted that a wide range of technological and engineering options is available for the building sector to become more energy-efficient with lower GHG emissions and has called for special attention to develop new and retrofit building envelopes; heating, ventilation, air-conditioning and cooling (HVAC) systems; and advanced energy management systems and their upgrades. It has also stressed the need to achieve passive and net zero energy standards for residential and commercial buildings, respectively with onsite alternative renewable energy options by 2030 and to implement smart and solar envelope concepts for large building complexes.

The CAETS Energy Committee has noted that most of the current HVAC systems are overdesigned for high factors of safety and has urged that future systems be based on scientifically evaluated heating / cooling peak loads. The advanced energy management systems based on computer aided controls, energy analytics and big data engineering are essential for making building sector respond to energy conservation principles proactively on a large scale. The CAETS committee has also noted the need to achieve a fine balance between technological, regulatory and administrative measures with appropriate incentives and disincentives. It has also seen tremendous opportunities for the application of frugal engineering concepts for developing low cost building materials and structures in emerging economies.

Though the five major constituencies of the transportation sector viz., road, rail, air, sea and pipeline systems currently rely heavily on fossil fuels, there are positive indications of their moving towards lower carbon energy regime. The current regulatory framework is predominantly emission reduction driven and needs to be reoriented towards energy efficiency. The CAETS Energy Committee has identified energy-efficient light vehicle engines, hybrid electric-diesel locomotives, advanced aero and marine engines and switchover to multimodal transport options as high priority areas for technology and engineering interventions. While identifying current and emerging priorities, the CAETS Energy Committee has specified implementable initiatives to maximise the potential impact of technological options in building and transportation sectors.

CHAPTER 1

GENERAL TECHNOLOGY AND ENGINEERING CONSIDERATIONS IN BUILDING AND TRANSPORTATION SECTORS

CHAPTER 1

1.0 Theme and target audience

The rapidly growing world energy demands and greenhouse gas emissions have raised concerns over exhaustion of energy resources and adverse environmental impacts on climate change. The building sector is responsible for approximately 32% of global energy consumption, of which 24% is consumed in the household sector and 8% in the commercial sector. Transportation sector, in turn, accounts for about 18% of the global energy consumption. Global emissions were around 35 billion tonnes of carbon dioxide in 2013. Under business-as-usual conditions, they are expected to grow to about 44 billion tonnes by 2030. There are many reasons for launching determined and focussed efforts to reduce emissions, not least of which is the threat of climate change. This report provides engineering and technology perspectives of the possibilities in these two sectors for significant and substantial reduction in the emissions, primarily by improved energy efficiency and partly by using lower-carbon sources of energy.

The possibilities for improvements in energy and emission reduction in the building sector are challenging for two reasons. Firstly, while there is a wide range of possible improvements in new buildings, many of which may be low cost and have rapid paybacks, change acceptance by both the building industry and its clients is painstakingly slow. There are many excellent standards, which can have a marked impact on the energy performance of new buildings. There is a need to incorporate these standards in the building codes to ensure their wider adoption. Secondly, unlike new buildings, much of the existing building stocks do not readily lend themselves to adoption of energy efficiency measures. There have been only small incremental improvements and they have an extended payback time and therefore not particularly economical. There are also issues such as heritage codes that prevent implementation of good practices such as, thermally efficient windows and doors, or the incorporation of alternative energy sources. Consequently, the pace of reduction in emissions from the building sector may be slow under business-as-usual approach. It is clear that inputs from policy-makers to encourage the wider use of the crucial engineering solutions need expeditious attention. The CAETS Energy Committee has provided a few potent directions to achieve significantly lower emissions from this sector by 2030.

AT PRESENT, THE PENETRATION RATE OF ALTERNATIVE FUELS AND ALTERNATIVE DRIVE TECHNOLOGIES IS LOW IN SPITE OF INCENTIVES AVAILABLE TO MAKE CHANGES.

In the transportation sector, there are ongoing incremental improvements in energy efficiency, many of which are already market-driven. There is a clear role for policy makers in several areas. First, there could be significant reductions if there were wider use of rail transportation for longer distance and inter-city freight movement and passenger traffic, possibly with a wider network of electricity-driven trains.

With increasing urbanisation in many parts of the world, there shall be stress on improved intra-city public transport to limit the demand for personal vehicles. In the area of personal transport, restrictions of both mass and power of the vehicle could have a large impact on the emissions. Fiscal measures could help facilitate a move from heavy, powerful vehicles to lighter, less powerful ones. Finally, use of lower-carbon fuels or hybrid drives (or both) could also play a significant role. At present, the penetration rate of alternative fuels and alternative drive technologies is low in spite of incentives available to make changes. There is a need to consider all these aspects while devising new policies and regulations. The engineering profession foresees an important role for development planners in finding ways and means to restrict the sprawl of the cities of the future, which should influence the energy performance of both dwellings and commercial buildings and the energy required to move goods and people within the cities. This approach could have larger impact on emissions.

This report has been prepared for CAETS Member Academies and their fellowships. It has identified and prioritised critical technological and engineering options to enable transitioning to a lower carbon economy in building and transportation sectors. The report can help facilitate member academies to formulate interfaces with their national governments, policy makers, technology leaders and concerned societies, based on the major findings of CAETS Energy Committee as presented in this report and specific contents relevant to their countries.

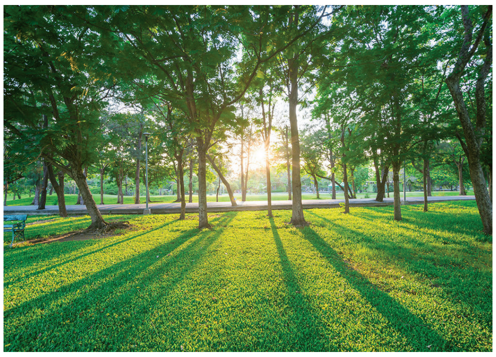
1.1 Global perceptions on lower carbon economy

Experts attribute much of the recorded increase in global average temperatures after the 1950s to the observed increase in anthropogenic GHG concentrations in the atmosphere. Reported studies indicate that if the growth in GHG emissions is unchecked, the global temperatures could increase by as much as 6°C by the end of 21st century (A1). Such a temperature increase could have large-scale humanitarian, environmental, political and economic consequence. The world, therefore, looks for new technological and engineering options coupled with appropriate policy framework to reduce the dependence on high carbon fossil fuels. Reduction in carbon emissions consequent upon a transition to a lower carbon economy accordingly holds the key.

REPORTED STUDIES INDICATE THAT IF THE GROWTH OF GHG EMISSIONS IS UNCHECKED, GLOBAL TEMPERATURES COULD INCREASE BY AS MUCH AS 6°C BY THE END OF 21ST CENTURY

However, creating a lower carbon economy will involve additional costs and technological and engineering inputs for emission abatement (A2). Development of commercially viable technological solutions to totally replace current energy systems based on fossil fuels and enhancing the efficiency of their utilisation cannot happen in short and medium time spans, unless right policies and technology perspective plans are made. The global experiences point towards achieving energy efficiency in building and transportation sectors as a key driver to fuel decarbonisation efforts. This aspect needs to be given due consideration.

Limiting global warming to less than 2°C has more or less become the de-facto target for global climate policy. The technological solutions to achieve this target are quite challenging. However, they are feasible through persistent efforts. The world needs to take immediate steps in this direction. Even a rise of 3-4°C would be catastrophic. In quantitative terms, limiting global temperature rise to 2°C means limiting CO_2 concentration in the atmosphere to 415 ppm and achieving a global CO_2 emission budget of 1,700 Gt CO_2e by 2050. The projected level of 14.3 Gt CO_2e in 2030 as against 11.1 Gt CO_2e in 2020 for building sector and 6.8 to 9.3 Gt CO_2e in 2030 as against 6.83 Gt CO_2e in 2010 in transportation sector have to be viewed under this context. In the case of the latter, the ``business as usual'' (BAU), ``expected normal'', and efficient ``transitioning to clean energy'' scenarios mean global temperature rises of 6˚,4˚ and 2˚C, respectively by 2050. In order to reach the 2˚C objective, rapid introduction of lower carbon vehicles and fuels has to necessarily take place as early as possible.



1.2 Technology and Engineering Issues

The complexities in adopting lower-carbon energy technologies mainly arise since continuation of the status quo requires less upfront investments and has minimum commercial risks. The support and active participation of all stakeholders is vital for creating new driving forces and incentives to facilitate a smooth transition to a lower carbon economy (A3).

Key elements for achieving these objectives are:

- To fix an appropriate time horizon to complete the transition process with measurable milestones
- To identify and evaluate technological and engineering options for energy and emission reduction
- To assess the sustainability of alternative technology and engineering options
- To accelerate the rate of absorption of most viable technology options through research, development and demonstration (RD&D)

A1: Climate Leaders, What is the UNFCCC and the COP? www.climate-leaders.org/climate-change-resource/India/India-at-co1(2014)

A2: T Naucler and P.A.Enkvist, Pathways to a Low Carbon Economy, Version 2 of the Global Greenhouse Gas Abatement Cost Curve, McKinsey & Co., (2009)

A3: M.Hafner etal, Transition Towards a Low Carbon Energy System by 2050, What Role for the EU? Report by European University Institute (RSCAS), Italy (2011)

- To create a new environment endowed with attractive job and business opportunities to counterbalance the additional cost of lower carbon economy systems

Result-oriented transition processes can bring multiple benefits to countries worldwide in terms of (a) Political, industrial and scientific leadership owning and supporting the transition plans; (b) Achieving a higher degree of sustainability in the development process; (c) Responding to climate change ahead of time; (d) Leveraging valuable national resources with high impact making energy and emission reduction options; and (e) Participate gainfully in new business initiatives (A4).

Over the last two decades, the world has invested substantial RD&D resources to advance lower carbon energy knowledge for commercial implementation. During the transition phase, the countries have so far moved along a path with minimal environmental risks by adopting appropriate technologies in an incremental fashion. The transition phase, therefore, has to be a much more dynamic period of technological change, innovation, learning, empowerment and entrepreneurship. In developing societies, the pace of these changes has to be so tailored that economic growth will be inclusive in nature.

STAKEHOLDERS WILL HAVE TO TAKE COMPLEX TECHNOLOGICAL DECISIONS WITH RESPECT TO ALTERNATIVE FUELS AND ENERGY-EFFICIENT SYSTEMS DURING THE PROCESS OF TRANSITION TO LCE.

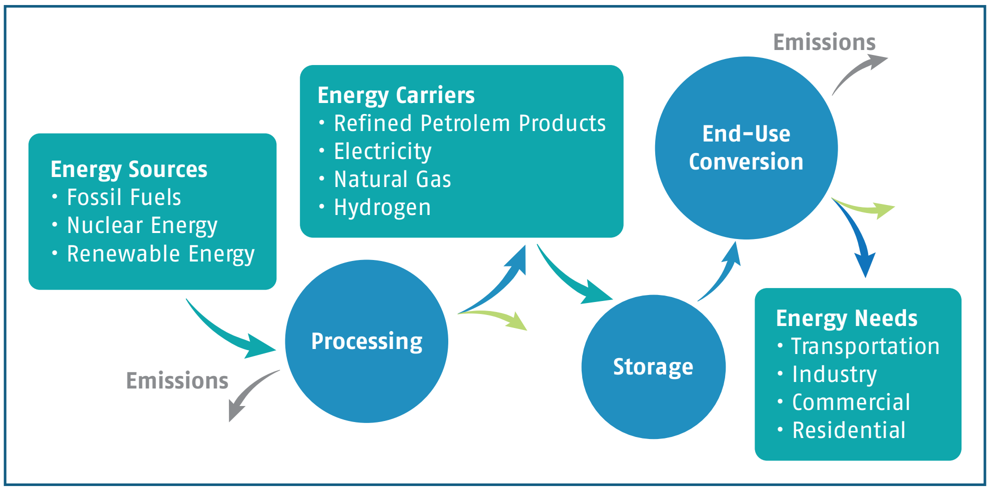


Fig: 1.1 Complete Energy Conversion Chain and the End Uses

The Stakeholders will have to take complex technological decisions with respect to alternative fuels and energy-efficient systems during the process of transition to LCE. Technology development always follows a dynamic process while engineering pathways are primarily concerned with the evolution of novel engineering systems and processes exemplified by design, control and manufacturing tools. The viability of technological and engineering options varies according to the geographical location, local climate conditions, available energy sources and their price structure, engineering and technology levels and supportive policy framework. The major issues associated with the building and transportation systems include linking technological and engineering pathways, quantitative evaluation of sustainable options, assessing prospective energy conversion chains, their life cycle and carbon footprints, and analysis.

For reducing the impact of energy use on the environment, the 'complete energy conversion chain' concept is a right and powerful approach. This approach can analyse any energy consuming process and show how we may begin the transition to a truly clean and sustainable energy future. Figure 1.1 shows a schematic of the generalised energy conversion chain. The chain starts with just three 'primary' energy sources and ends with a number of representative large end-use applications such as building heating and cooling, transportation, and industrial processes. In between the primary source and the ultimate end-use are a number of steps in which the primary source is converted into various types of energy 'carriers', or is stored for effective and efficient use.

A4: Wikipedia, Clean Development Mechanism of Kyoto Protocol, en.wikipedia.org/wiki/clean_Development_Mechanism(2011)

THE REPORT FOUND THE NEED FOR SIGNIFICANT INVESTMENTS TO SCALE-UP THE DEVELOPMENT AND DEPLOYMENT OF THE ENERGY TECHNOLOGIES AND RELEVANT POLICY ACTION AT NATIONAL LEVEL.

1.3 CAETS initiatives on lower carbon energy

The CAETS Board constituted a working group in 2009 for Low Carbon Energy with membership from ATSE (Australia), CAE (Canada), ACATECH (Germany), INAE (India), EAJ (Japan), NAEK (Korea), SAAE (South Africa), and RAE (UK). It produced the first report, on "Deployment of Low Emissions Technologies for Electric Power Generation in Response to Climate Change" in November 2010. Its focus was on the key technological issues faced in the deployment of low emission technologies for supplying electrical energy to meet the world's energy needs. It examined engineering challenges, key technologies for developing economies and the role of government. It contained country reports from the member academies. Dr. Vaughan Beck of ATSE, Australia compiled and coordinated the report.

The next report, on "Opportunities for Low-Carbon Energy Technologies for Electricity Generation to 2050" was published in June 2013, with the same academies involved, with the exception of EAJ and the addition of NAE (USA). The report highlighted engineering and financial risks in the deployment of low carbon technologies and the mechanisms to overcome them. The report contained chapters on technology costs, technology assessments (focussing on nine LCE technologies) and technology overviews. The report found the need for significant investments to scale-up the development and deployment of the energy technologies and relevant policy action at national level. The working group under the chair of Dr. Vaughan Beck of ATSE, Australia compiled the report.

The topic of the current report is "Transition to a Lower Carbon Economy – Technological and Engineering Considerations for Building and Transportation Sectors". Here, the CAETS Energy Committee examines the technological and engineering issues, which facilitates transitioning to a lower-carbon economy. Since each country may undergo a different transition process, the analysis in the report is global and generic in nature. The CAETS Energy Committee recognised that it has neither the resources nor the expertise and time to address non-technological issues involved in transition to a lower-carbon economy and instead focused on reviewing the technology and engineering options necessary to move towards a lower-carbon economy. It is aware that a wide spectrum of energy efficiency initiatives are needed, from lowest-hanging fruits such as energy-efficient system designs to cutting-edge technologies for fuel de-carbonisation. INAE Drafting Committee led by Dr. K V Raghavan, FNAE, India, has compiled the report. Dr. KV Raghavan and Dr. Baldev Raj, FNAE, India, have edited it jointly.

The CAETS Board upgraded the Working Group on Energy into a full-fledged Energy Committee in 2013 with the Chairmanship and Secretariat passing from ATSE, Australia to INAE, India. The members of the newly constituted CAETS Energy Committee met at Cape Town, South Africa on 29th and 30th November 2013 and discussed the precise contents of the report, targets for its completion and the need to highlight the achievements in energy/emission reduction in building and transportation sectors, which could inspire future developments. They later met at Beijing, China in June 2014, Berlin in November 2014 and in London in May 2015 to formulate and review the progress of the report. The Beijing meeting stressed the need to make the report engineering intensive befitting the academic eminence of CAETS fellowship. The Berlin meeting specified the target audience and the need to bring out the appropriate technology-related issues. The London meeting evolved an attractive format for communicating technology-oriented findings of CAETS Energy Committee to the policy makers and senior engineers in an effective fashion. It had also given green signal for release of electronic version of the report at the CAETS CONVOCATION-2015 held on 13th and 14th October 2015 at New Delhi, India.

CHAPTER 2

ENGINEERING FOR ENERGY EFFICIENCY AND EMISSION MITIGATION IN BUILDING SECTOR

CHAPTER 2

2.0 Preamble

The building sector worldwide is worth US$ 7.5 trillion accounting for 10% of global GDP. The main constituencies of the building sector are residential and commercial segments. For working towards their transition to low carbon economy, they need to be sub-classified into new and existing buildings, those in different climatic zones, and those with different end uses viz., housing, schools, colleges, food outlets, hotels, warehouses, shopping centres, etc. The lifespan of buildings ranges from 35 to 70 years, depending on the type of buildings, quality of construction, maintenance and geographical location.

As a physical setting, the building environment is critical for ensuing good quality of life for its occupants. It will express their personality, culture and lifestyle. The context in which the buildings are situated is also important. Unlike developed countries, the choice of housing is the privilege of wealthy in most of the developing societies. Their governments are trying to reduce these disparities. The concept of smart buildings is to enhance the living experience of their occupants. For example, India, expected to emerge as the world's 3rd largest construction market by 2020 with a target of adding 11.5 million residential buildings every year, has placed emphasis on developing smart cities. Low cost smart buildings have already seen some level of traction in a few Indian cities. Smart building concepts are thus redefining the role of buildings in the everyday life of people in developed economies.

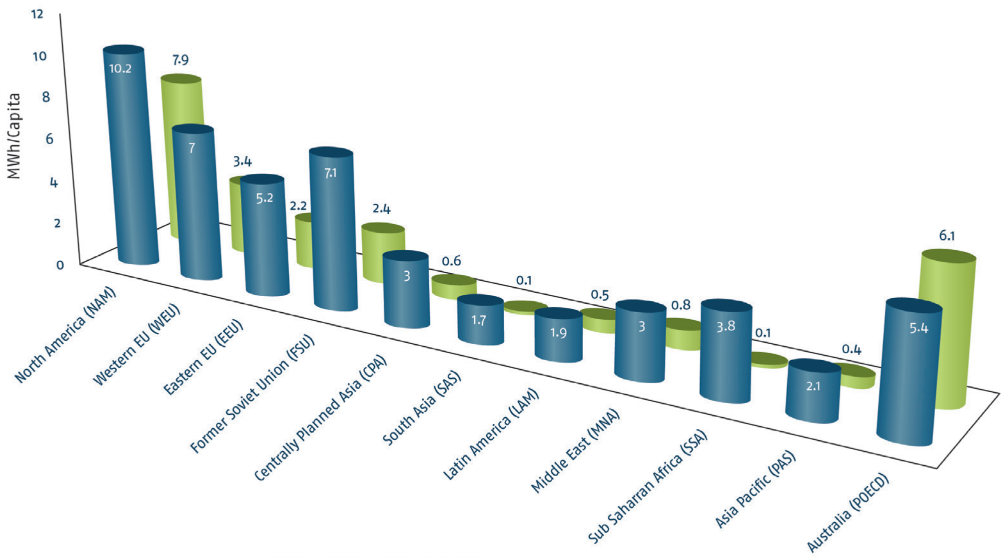
SMART CONCEPTS ARE REDEFINING THE ROLE OF BUILDINGS IN THE EVERYDAY LIFE OF PEOPLE.

2.1 Global building energy and emission scenarios

2.1.1 The Energy Consumption, End use Patterns and Growth Regions

As per reports (B1), the worldwide energy consumption in the building sector was 32.5 billion MWh per annum in 2010 with residential and commercial buildings accounting for 67% and 23%, respectively. This could rise to 52.7 billion MWh per annum in 2040, with an anticipated annual growth rate of 1.6%. The Intergovernmental Panel on Climate Change (IPCC) at its meeting in Geneva, Switzerland (B2) has projected that the global energy in building sector could nearly double by 2050 under business as usual scenario. Considering an estimated 0.8 billion people require new housing and nearly 4.3 billion people needing modern energy resources for their

Fig.:2.1.1: Annual Per Capita Energy Use in Building Sector for Various World Regions



Data Cited in Ref B31

B1: IEA Online Data Services., http://data.iea.org/ieastore/statislisting.asp

B2: O.Lucon and D.U.Vorsatz., Buildings: Climate Change 2014: Mitigation of Climate Change. Chapter 9 of 5th Assessment Report (ARC) of IPCC, Cambridge, UK and USA (2014)

Table 2.1.1a.: Projected Building Energy Growth Regions (2010-40)

Region	Growth in Energy Consumption		Growth Pattern	
	Residential	*Commercial*	*Residential*	*Commercial*
North America (NAM)	0.25	0.2	Low	Low
Western Europe (WEU)	0.15 (-ve)	0.1	Negative	Low
Eastern Europe (EEU)	0.05 (-ve)	0.1	Negative	Low
Latin America (LAM)	1.2	0.3	Moderate	Moderate
Former Soviet Union (FSU)	0.4	0.25	Low	Low
Middle East &North Africa (MNA)	0.85	0.15	Moderate	Low
South Asia (SAS)	4.25	1.2	Very High	High
Centrally Planned Asia (CPA)	1.05	1.7	Moderate	High
Sub Saharan Africa (SSA)	1.15	0.2	Moderate	Low
Asia Pacific (PAS)	0.75	0.25	Moderate	Low
Pacific OECD (POECD)	0.2 (-ve)	0.05	Negative	Very Low

Data Reported in Ref B2

CHINA AND INDIA WILL LEAD THE FUTURE WORLD GROWTH IN BUILDING ENERGY WITH A THREEFOLD INCREASE ANTICIPATED BETWEEN 2010 AND 2040.

existing housing, the projected growth looks reasonable. Fig.2.1.1 depicts the variations in annual per capita energy consumption for the residential and commercial building sectors in various regions of the world (B2).

USA, Australia, Canada and Germany were front-runners in terms of per capita energy consumption from buildings, resulting from diversity of end uses as reported in 2010. In terms of emission quantity, USA, EU-25 and China were reportedly major contributors. In terms of energy consumption growth, the data presented in Table 2.1.1a shows that during the last two decades, the per capita energy consumption in countries of North America (NAM), Western Europe (WEU), former Soviet Union (FSU) and Australia (POECD) has grown only modestly in residential buildings, even though they recorded world's highest per capita energy consumption.

Among the emerging economies, Centrally Planned Asia (CPA) including China, South Asia (SAS) including India and Middle East and North Africa (MNA) are the dynamic growth regions. They will experience rapid economic growth (>3% per annum) as the living standards of their population rise. China and India will lead the future world growth in residential energy consumption with a three-fold increase anticipated between 2010 and 2040. Their energy requirement for the building sector could be 6.65 billion MWH/yr. in 2030.

The United Nations Environment Programme (UNEP) has estimated a reduction of 30-80% in energy consumption in buildings worldwide (B3). The range is so wide because of the diversity of end uses, regional influences and dominance of local agencies in building construction with different levels of energy saving sensitivities. It is also due to the energy efficiencies attributed to the various commercially proven technologies, energy saving practices adopted and the recommended energy-efficient systems and devices. The energy end use in buildings varies depending on climatic zones, socio-economic status of owners/occupants, technological developments and general life style of local people (B4). Table.2.1.1b shows the variations in energy end use in residential and commercial buildings in hot and cold climates. The impact of space heating/cooling and water heating on energy consumption is quite high in commercial buildings in both hot and cold climates whereas their impact in residential buildings is restricted to cold climates only.

B3: UNEP-SBCI., Buildings and Climate Change: Summary for Decision Makers. UNEP-SBCI Report, Paris, France (2009)

B4: GEF, Promoting Energy Efficiency in Buildings: Lessons Learned from International Experience, A UNDP Report (2010).

WHILE ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS IS CLIMATE AND LIFESTYLE RELATED, THE SAME IS CLIMATE, ENDUSE AND PUBLIC UTILITY RELATED IN COMMERCIAL BUILDINGS

With reference to appliances, light and air-conditioning use nearly 70% of energy in commercial buildings whereas fans and refrigeration units consume maximum energy in residential buildings. Their use within the residential building sector varies since they are lifestyle related. Significant differences occur in lighting power densities, heating and cooling loads and insulation levels in hot and cold climate zones. The primary energy consumption of commercial buildings in USA is reported to vary (B5) from 300 to 1,500 kWh/m² depending upon the end use viz., office, education, warehousing, healthcare, public utility and lodging. The average energy consumption of space and water heating, refrigeration, office equipment and cooking are reportedly 53, 16, 10 and 1.3 kWh/m² respectively in USA (B6).

Table 2.1.1b: Energy End Uses in Buildings in Hot and Cold Climatic Zones

End Use Application		Percentage Share			
		Residential		Commercial	
		Hot	Cold	Hot	Cold
1	Space Heating	2	24	15	12
2	Space Cooling	9	10	14	13
3	Water Heating	2	12	7	7
4	Refrigeration	28	7	4	4
5	Lighting	15	12	27	25
6	Ventilation	14	3	6	7
7	Electronic Systems	3	8	7	9
8	Cooking	12	6	--	--
9	Wet Cleaning	3	7	3	2
10	Others	12	11	17	21
Total		**100**	**100**	**100**	**100**

2.1.2 Alternative Lower Carbon Energy Options

There is a variety of energy options available for building sector, from non-renewable sources such as petroleum oil, natural gas, coal, wood and coal based fuels to low or no carbon sources such as biofuels, solar, wind, hydroelectric and geothermal energy.

The International Energy Agency (IEA) in 2010 broadly examined the renewable energy transitions anticipated during 2008-35 in the building sector (B7). It has found that the potential for increased penetration of modern renewables (MR) viz., biomass, solar and geothermal into the building sector is very high. In developing countries, where new building growth is very rapid, opportunities exist to install MR technologies at the outset itself. The share of MR in meeting total heat demand in buildings could be much more substantial in OECD countries during 2008-35. While the solar energy contribution in MR is much higher in non-OECD countries, the biofuel contribution is relatively higher in OECD countries. The overall share of MR in building sector worldwide could increase to 16% by 2035.

THE BOOM IN 1ST GENERATION BIOFUELS ARE GETTING OVER DUE TO LAND, DEFORESTATION AND FOOD RELATED ISSUES.

The boom in 1st generation biofuel is getting over due to land, deforestation and food-related issues. This sector has been going through a renaissance in the form of 2nd generation biofuels in the recent years. They include biofuels based on lignocellulosic biomass, biomass to liquid (BTL) and biosynthetic gas. They have good potential to provide energy equivalent to 1.7 billion MWh/annum in near future (B8a). Biodiesel has a high potential for space heating in buildings. Few blends of biodiesel are already in use as heating fuel in some parts of USA.

B5: Centre for Sustainable Systems (USA), Commercial Building. Fact Sheet No.CSS05-05(2013)
B6: US Energy Information Administration, Annual Energy Outlook 2012 with Projections to 2035, Document NO.DOE/EIA-0383(2012)
B7: IEA, World Energy Outlook-2010., OECD/IEA Report with ISBN: 9789264086241 (2010)
B8a: A.Eisentrant., Sustainable Production of Second Generation Biofuels: Potential and Perspectives in Major Economies and Developing countries. Information Paper from OECD/IEA (2010)
B8b: A.Wilson., The Folly of Building Integrated Wind, https://www2.buildinggreen.com/print/article/folly-building-integrated-wind (2009)

BUILDING INTEGRATED WIND HAS SO FAR NOT LIVED UP TO ITS POTENTIAL DUE TO ENGINEERING CHALLENGES

Wind turbines integrated with tall buildings have been receiving global attention since 1970s, as the wind speeds increase with height. Building geometry can also alter the wind turbine performance. Wind scoops can be part of the structure of buildings themselves. Building integrated wind has so far not lived up to its promise due to scientific and engineering challenges as well as economic non-attractiveness (B8b). Rooftop installations are too small to be cost effective and the airflow is too turbulent to harvest efficiently. There is need for more engineering advances.

Solar PV has very high potential in energy-efficient buildings with an ability to meet near zero or net positive energy commitments. Geothermal energy systems use 25-50% less electricity than conventional systems. Water-to-air and water-to-water geothermal systems of 1,500 KW capacity are commercially available (Appendix A1.2). The commercial feasibility of solar-geothermal hybrid systems for space and water heating/ cooling applications in buildings is found to be high with a payback period of 6-9 years (depending on the size) based on life cycle costing.

CO_2 EMISSIONS FROM RESIDENTIAL BUILDINGS INCREASED AT A MUCH SLOWER RATE (0.1% PER ANNUM) DURING 2001-08 THAN DURING PREVIOUS 30 YEARS WHEREAS THESE EMISSIONS FROM COMMERCIAL BUILDINGS GREW AT 3% PER ANNUM DURING THE SAME PERIOD.

2.1.3 Worldwide GHG Emissions from Buildings and their abatement potential

Globally, efforts at reducing GHG emissions (fine carbon particulates, CH_4, HFC_s, SF_6, OH and aerosols) from the building sector have had a mixed record of success since the large stock of existing buildings still operate at low level of energy and operational efficiency. The IPCC and Imperial College, London (B9 and B10) placed the GHG emissions from the building sector including through electricity use at about 8.6 Gt CO_2 with an average growth of 2% (2.5% in commercial and 1.7% in residential buildings) during 1971-2004. Direct emission from the building sector was of the order of 3Gt CO_2 in 2004. The rest of the emissions are attributed to the electricity supplied to the buildings. The IPCC (B10) later reported that CO_2 emissions from the residential buildings had increased at much slower rate of 0.1% per annum during 2001-08 than the previous 30 years (1.4% per annum), whereas the emissions from commercial buildings had grown at a faster rate of 3% per annum during 2002-07 than the previous 30 years (2.2% per annum).

The UNEP's Sustainable Buildings and Climate Initiative (UNEP-SBCI) Report (B3) and the fourth Assessment Report of IPCC (B10) have projected the GHG emission levels at 11.1 Gt CO_2 eq in 2020 and 14.3 Gt CO_2 eq in 2030. It is based on a scenario of local solutions to environmental problems, more than moderate increase in global population, intermediate to rapid level of economic development and between less and rapid technological changes. The per capita emissions pertaining to building sector in selected world regions/ countries are reported in 2002 (B11). It showed that USA, EU-25, Russia, Australia, India and China are the major countries with their absolute GHG emissions from buildings ranging from 240-2,000 Mt CO_2 eq. The per capita emissions from USA, EU-25 and Russia were high and they ranged from 7 to 1.5 T CO_2. The variations are due to the degree of electrification achieved, level of urbanisation, amount of building area per capita, climatic condition and nature of government policies to promote efficiency. It is important to note that the abatement potential of future buildings will be significantly high due to several changes occurring in the basic thinking of building engineers. Though reducing the carbon emission has been an important focus area in the building sector right from the 1990s, the understanding of what exactly constitute carbon footprints has undergone significant changes in recent times.

The ``life cycle'' approach has now been accepted as the best method for assessing the carbon footprints of a building. The energy and carbon implications of building materials and emission potential during the construction phase have been receiving much more attention in recent years. The analysis boundaries for life

B9: Grantham Institute for Climate Change. Reduction of CO2 Emissions in the Global Building Sector to 2050., Report GR3 from Imperial College, London (November 2011).
B10: M.D.Levine etal, Residential and Commercial Buildings, 4th Assessment Report (AR4) of IPCC, Cambridge, UK (2007).
B11: K.A. Baumert, T.Herzog and J.Pershing. Navigating the Numbers: GHG data and International Climate Policy., A Report from World Resource Institute; ISBNL1-56973-599-9(2005)
B12: IPCC Technologies Policies and Measures for Mitigating Climate Change. IPCC Technical Paper 1 for UN Framework Convention on Climate Change, November (1996)

SIMULTANEOUS MONITORY OF GHG EMISSIONS AND ENERGY CONSUMPTIONS NEED TO FORM THE CORERSTONE OF NATIONAL CLIMATE CHANGES MODERATIONS POLICIES.

DRAWBACKS OF PREASSESSING EMISSION MITIGATION PROSPECTS THROUGH MODELLING ARE DUE TO UNSATISFACTORY VISUALIZATION OF GROUND SCENARIOS, SUB-OPTIMAL MACROECONOMIC POOR FEEDBACK ON ENERGY AND ECONOMY AND LACK OF CONSISTENCY ACROSS VARIOUS STUDIES.

cycle analysis have also undergone significant changes with focus on most capital-intensive items rather than all processes and elements involved in building construction. There is also a broader appreciation in public domain on reducing the carbon footprints of buildings to make them climate friendly. The strong link between energy efficiency and emission reduction is being realised by the engineering community for developing lower carbon energy buildings. These green choice options are providing powerful stimulus for developing design options for smart buildings. Various avenues exist for promoting the carbon habit amongst the building stakeholders.

The IPCC (B12) projected the globally achievable emission reduction in the building sector to lie in the range of 0.25 – 0.7 Gt CO_2 eq per annum by 2020 and 0.35 – 2.5 Gt CO_2 eq per annum by 2050 anticipating a big gap between projected and achievable emission reductions. These predictions follow IPCC baseline scenarios on the population, income and fossil fuel resources in 1990.

It is important to recognise that understanding the full implications of GHG emissions on climate change is a slow process. The climate sensitivity normally increases with damages caused to the environment. Close monitoring of GHG emissions and energy consumption must therefore form the cornerstone of every national climate change strategy. Cost effective emission reductions and energy savings of around 30% are possible in many countries of the world. Policy makers and building industry stakeholders have to identify the economically viable priorities at national level. There is also a need to understand that countries will not meet GHG emission targets without achieving energy efficiency gains in the building sector.

McKinsey & Co assessed the emission abatement potential of global building sector as 3.52 Gt CO_2 eq per annum by 2030 with 68% from residential and 32% from commercial building sectors (B13). They have identified 26 abatement options grouped into six categories. Fig.2.1.3a provides their individual emission abatement potential. The new energy-efficient building packages, based on passive energy saving concept, could reduce the site energy consumption from 115 to 35 KWh/m^2. The retrofit building envelope packages, based on air tightness improvement, weather stripping of doors/windows, better insulation of wall cavities, glazing and mechanical ventilation, could bring down site energy consumption from 70 to 25 KWh/m^2 in two levels. The efficient HVAC package involves moderate level of replacement of existing devices with high efficiency systems. Improved water heating package involves retrofitting existing systems with higher efficiency systems with moderate penetration of solar powered units. The appliances and electronics package offers moderate replacement with energy-efficient electronics. The energy-efficient lighting package offers replacement of existing fittings with LED and super-efficient fluorescent systems. The McKinsey studies also indicate that changes in user behaviour could reduce CO_2 emissions by as much as 1.5 Gt CO_2e per year in 2030.

The CAETS Energy Committee has noted that an order of magnitude difference exists between the projections made by the IPCC and McKinsey & Co., since the basis of their assessment is very different. The IPCC's estimates are scenario based with consideration of environmental, population increase, economic development and anticipated technological changes, whereas McKinsey's estimates are based on abatement options grouped into specific categories.

Pre-assessing Emission Mitigation Prospects

The CAETS Energy Committee has noted that a wide range of models has been reported with uncertainties of energy-efficient technologies and energy sector interactions with the national economies under their respective assumptions. Wedge and service driven models pre-assess carbon emission reduction under varying socioeconomic and technological conditions (B14 to B16a). Top-down and bottom-up approaches have been reported (B16b) with focus on energy-efficient technologies and dynamics of

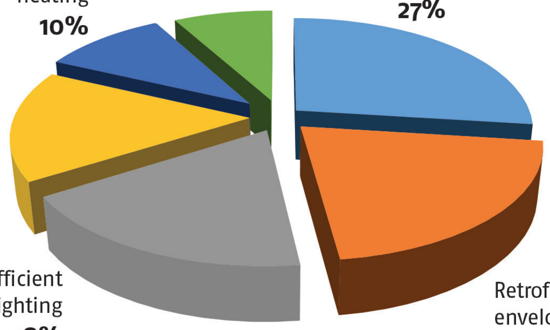
B13: McKinsey and Co., Pathways to a Low Carbon Economy: - Version 2 of the Global Greenhouse Gas Abatement Cost Curve. A Report from McKinsey & Co., (2009)
B14: S.Pacala and R.Socolow. Stabilization Wedges: Solvent Climate Problem for the next 50 years with Current Technologies., Science 305 (5686), 968-972 (2004)
B15: Z.Hausfather, What is behind the 'Good News' declines in US CO2 Emissions? http://www.yaleclimatemedia forum.org /2013/05
B16a: F.Rong, L.Clarke and S.Smith., Climate Change and Long Term Evolution of US Building sector., US Pacific Northwest National Laboratory Report No.PNNL-SA-48620 for US$OE Contract DE-AC05-76RLO 1830 (2007)
B16b: D.P.Van Vuuren, M.Hoogwijk, T.Barket eta., Comparison of To-down and Bottom-up Estimates of Sectoral and Regional GHG Emission Reduction Potentials., Energy Policy, 5125-5139 (2009)

SCENERIO BASED MODELING IS EMPLOYED FOR PRESCRIBING EMISSION TARGETS DURING BUILDING RETROFITTING.

market processes to assess the building sector emission reduction potential by 2030. Semi-empirical and multicomponent models evaluate the emission reduction potential of buildings considering technological advances, variations in energy demand of devices and weather effects (B16c). They were applied to Scottish housing projects to assess the impact of different policy interventions aimed at reducing CO_2 emissions from residential buildings. Interestingly, the International Council of Chemical Associations (ICCA) employed scenario based modelling (B17) for prescribing emission targets based on the extent of building improvement and retrofitting.

After a brief review of the above models, the CAETS Energy Committee has observed their drawbacks with reference to visualization of macroeconomic feedback on energy and other sectors of the national economies and lack of consistency across various studies. From engineering perspective, there is a need to develop more rigorous multicomponent building emission models, based on building demographics, thermal physics, economy related factors, policy interventions and anticipated changes in consumer behaviour patterns. These models need validation with more extensive experimental data and should be country specific.

Fig.2.1.3a: Emission Abatement Potential of Various Building Component Packages.



THOUGH LIFE CYCLE ANALYSIS IS PERCEIVED AS A COMPLEX AND TIME CONSUMING INITIATIVE, IT IS BECOMING MORE USER FRIENDLY THROUGH MODELLING AND SIMULATION

GHG Emissions under Life Cycle Framework

The life cycle framework of a building (Fig.2.1.3b) covers manufacture of building materials (embodied energy), their transportation to building sites (grey energy), their construction (induced energy), operation (operational energy) and refurbishment or demolition (B18). On an average, over 80% of GHG emissions occur during operational phase and around 10-20% emissions take place during material manufacture, transportation, building construction, maintenance and demolition. While the construction phase emissions occur within a short time frame, the operation phase emissions will continue for a long time (say 25 to 30 years).

The UNEP and international energy ranking systems have been promoting Life Cycle Approach [LCA] concept in the building sector for more than a decade. Though LCA has been perceived as complex and time consuming, it is getting more user friendly by the use of computer-aided assessment tools such as ATHENA, SIMAPro, GaBi and E10 (B19 to B23). The Hong Kong Housing

B16c: Scottish Government Social Research, Modelling GHG Emissions from Scottish Housing. A Report by Cambridge Architectural Research, Cambridge Econometrics, Roger Talbot 2 Associates Ltd., and Alembic Research (2009)

B17: ICCA Building Technology Roadmap, International Council of Chemical Associations (ICCA), Brussels, Belgium (2010)

B18: A.Saynajoki, J.Heinonen and S.Junnila., A Scenario Analysis of the Life Cycle Greenhouse Gas Emissions of a New Residential Area., Env.Res.Letters 7(3), 1-17 (2012)

B19: LCA Data and Software, Athena Sustainable Materials Institute, Impact Estimator V5 (2014)

B20: PRE Consultants, Sima Pro 5.1: Instructions Eco-indicator 99 Update (2003); Sima Pro 6: Introduction to LCA with SimaPro (2004)

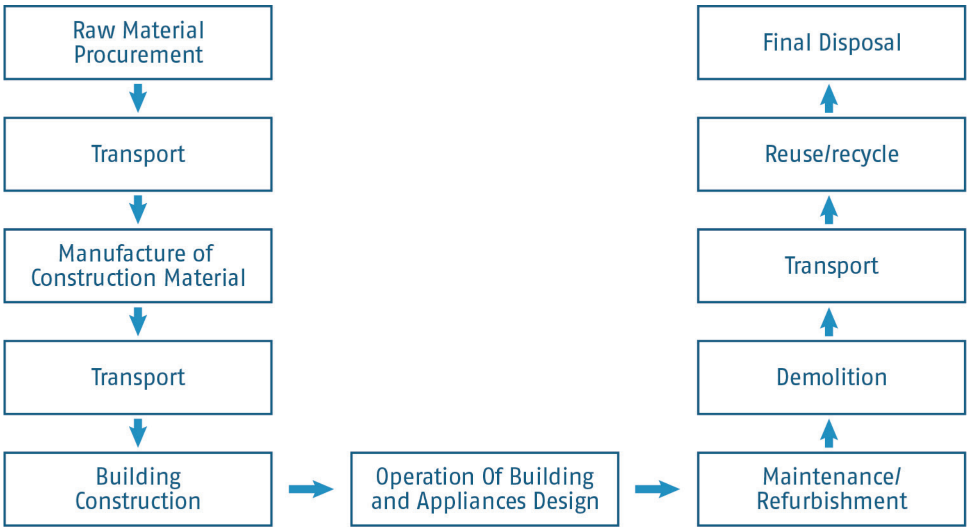
B21: PE International., GaB94 Software System and Databases for Life Cycle Engineering, Stuttgart Echterdingen: PE &LBP (2011)

B22: C.Hendrickson, A.Horvath, S.Joshi, O.Jaurez, L.Lave, H.S. Mathews, F.C.McMichael and E.Cobas-flores., Economic Input-output Based Life Cycle Assessment (EIO-LCA), Carnegie Mellon University (2011)

B23: J.Oschendorf, L.K.Norford, D.Brown, H.Durschlag, S.L.Hsu, a.Love, N.Sanero et al., Methods, Impacts and Opportunities in the Concrete Building Life Cycle., Report from Concrete Sustainability Hub of the Massachusetts Institute of Technology (2011)

Authority prepared LCA studies as early as 2005 to identify sustainable building materials for housing complexes (B24).

Fig.2.1.3b: Typical Life Cycle of a Building



PREFABRICATED STEEL BUILDINGS CONTRIBUTE TO A SIGNIFICANT INCREASE IN EMBODIED ENERGY. BUT THEY CAN HELP SAVE THE ENVIRONMENT THROUGH MATERIAL REUSE.

The LC concept has provided an interesting case study (B25a) of an eight storey multi-residential building (3,943 m^2 area) in which a steel structured prefabricated option resulted in 78% material saving compared to conventional concrete construction. However, the prefabricated steel building resulted in a significant increase in embodied energy. The LC analysis also showed the significant potential for material reuse in prefabricated building option representing up to 81% saving in embodied energy and 51% material saving by mass. The LCA research studies at the Massachusetts Institute of Technology in USA (B25b) have shown that for residential buildings, insulated concrete buildings offers 20% operational energy savings over the lifetime as compared to wood framed buildings. In case of commercial buildings, low carbon structural concrete lowered the life cycle carbon emissions significantly. The studies demonstrated that measurable differences exist between alternative construction systems over a life span of 75 years.

2.2 Classification, ratings, measurement and case studies of energy-efficient buildings

2.2.1 Energy Classification of Buildings

Classification enables one to assess the extent of energy conserved or generated on-site in a building and its overall consumption. It facilitates the fixation of appropriate benchmarks for energy reduction to make them more sustainable.

Passive Energy Buildings

The passive energy saving concept provides the first level GHG emission abatement solution to the building sector. The MINERGIE rating used in Switzerland uses this concept. There is a need to ingrain it in the modern building technologies fully. From engineering perspective, it favours an integrated design approach with focus on reducing energy consumption in space heating/ cooling by optimizing its insulation, ventilation, orientation, air tightness, thermal bridges, comfort level of windows and heat recovery. Its large scale implementation across the world can contribute up to 27% of emission abatement in the building sector by 2030. The international

B24: The Hong Kong Housing Authority., Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) Study of Building Materials and Components., Final Report under Agreement No.CB20020024., July (2005)

B25a: L.Aye, T.Ngo, R.H.Crawford, R.Gammampila and P.Mendis, Life Cycle GHG Emissions and Energy Analysis of Prefabricated Reusable Building Modules, Energy and Buildings, 47, 159-168 (2012)

B25b: J.Ochsendorf, LCA of Buildings Concrete Sustainability Hub, A Report from Massachusetts Institute of Technology, December (2010).

THE HELIOTROPE IN FREIBURG IN GERMANY IS REPORTEDLY THE WORLD'S FIRST POSITIVE ENERGY BUILDING IN 1994.

guidelines for passive building design concept prescribe building heating/cooling demand to be less than 10-20 KWh/m²/year depending on the climatic condition and the air leakage from the building envelope not to exceed 0.6 times the house volume per year at 50 Pa (N/m²). The number of passive buildings worldwide in 2010 was around 25,000 built by incurring an additional 6-16% construction cost (66-265 US$/m²)

Net Zero Energy Buildings

Conceptually, they produce as much energy as they use per unit time. They employ exemplary designs to minimise energy requirements and use renewable energy systems to meet the additional energy demands. The NZEB concept prescribes energy efficiency as first priority and employs renewable energy sources on-site. Around 300 net zero energy buildings exist in the world. Some net zero energy retrofits are also available for existing buildings.

Net Positive Energy Buildings (NPEB)

They are based on extended net zero energy concept to produce more energy than they consume. The Heliotrope in Freiburg in Germany is reportedly the world's first positive energy building. The need is to generate minimum waste and demand minimum water requirement. They have to capture, treat and reuse all water on-site. Their basic concept is more than just a method of producing environment friendly housing since they have to adopt integrated ecological and engineering concepts such as using phase change materials and vacuum insulation in the walls. The solar panel structure rotates to track the sun to maximise sunlight inputs and employs CHP (combined heat and power). An interesting example of NPEB is the Saint Gobain's Multi-comfort concept for housing evolved in 2004 (B72). It employs high performance materials for meeting energy efficiency, visual, health and acoustic requirements with guarantees on real living comfort. It uses bioclimatic architectural design, which makes maximum use of solar warmth and light. The materials used have low environmental impact throughout the building's life cycle.

2.2.2 Building Energy Rating Systems

A building energy rating system provides an indication of its energy performance in terms of space and water heating/cooling, ventilation and lighting calculated on the basis of standard occupancy. Its method of calculation and related legislation may vary from country to country. For achieving transition to a lower carbon economy, energy certification of buildings acts as a key instrument for reducing energy consumption and improving the energy performance of new and existing buildings.

Worldwide, building energy rating and disclosure mandates are being established since national policy makers are becoming more attuned to them as important market driving forces. The European Union's Energy Performance of Buildings Directive (EPBD) is being adopted in several European countries. The International Green Construction Code provides a set of rules that establish as minimum requirements for elements of green buildings (B26). The new ISO 21931-2010 Standard (B27) provides the necessary framework for assessing the environmental performance of building construction works and is intended to be used in conjunction with the above standards and codes. The IEA has established (B28) the BEED database containing detailed information covering 448 building energy codes from 34 countries, 240 labelling schemes and 219 incentive programmes. It provides valuable information on each policy instrument developed and/or implemented by the IEA member countries.

The CAETS Energy Committee is of the opinion that the current regulations in building sector are predominantly GHG emission control driven. Targeting energy efficiency and GHG emission reduction in an integrated fashion will be most desirable from implementation point of view eventhough they have their

B26: International Green Construction Code for Buildings; American Institute of Architects. 2012

B27: ISO 21931-1:2010, Sustainability in Building Construction – Framework for Methods of Assessment of the Environmental Performance of Construction Works – Part 1: Buildings (2010)

B28: IEA, Modernizing Building Energy Codes: To Secure Our Global Energy Future., The IEA Policy Pathway Series Report by OECD/IEA (2013)

B72: a) The Saint-Gobain., Multi-comfort Construction., www.saint-gobain.com/en/solutions/.../multicomfort-construction

b) The Saint-Gobain., Multicomfort Renovation., www.saint-gobain.com/en/solutions /... / multicomfort-renovation

CURRENT BUILDING REGULATIONS ARE PREDOMINANTLY GHG EMISSION CONTROL DRIVEN

own dynamics and time scales for devising technology and engineering interventions. Integrated regulations have to be technology neutral. Attribute-based regulatory framework based on mathematical functions to provide quantified energy economy and emission reduction targets will be most preferred. The CAETS Energy Committee is aware of such efforts being made by some international and national regulatory bodies. It would like to stress the urgency for implementing the integrated regulations worldwide.

2.2.3 Measurement and Verification of Energy Performance of Buildings

Measurement and Verification (M&V) are important tools of energy-efficient building performance evaluation (B29). There is a host of engineering tools to perform online as well as offline measurements to validate the invested time, effort and cost for energy and emission reduction in new buildings and retrofitting of existing buildings. M&V studies require an in-depth knowledge of instrument physics, power digital electronics, computer assisted response measurements, flowmetry, thermography, image processing, modelling, and simulation, among other things.

A HOST OF ENGINEERING TOOLS CAN BE EMPLOYED TO PERFORM ONLINE AND OFFLINE MEASUREMENTS TO VALIDATE THE INVESTED TIME, EFFORT AND COST ON ENERGY/EMISSION REDUCTION IN EXISTING AND NEW BUILDINGS.

Current transformers and transducers can sense alternating current. Power digital sampling meters can evaluate inductive loads of motors and magnetic ballasts. Battery powered monitoring devices can record equipment time on stream performance. Intrusive, ultrasonic and magnetic flow meters can measure liquid flow. IR thermography can not only assess exterior and interior thermal anomalies in building envelopes (B30) but also help in energy performance modelling. The latter helps to predict energy usage in building with and without planned energy/emission reduction initiatives. A three-dimensional finite element (FEM) analysis (B31) predicts the thermal performance of building envelopes containing high conducting thermal bridges under steady and transient conditions. There is also a variety of statistical tools to quantify, evaluate and reduce uncertainties in M&V analysis. The CAETS Energy Committee foresees more advances in M&V engineering through the employment of smart energy sensors, energy performance analytics and interactive devices for smart electric grids for establishing the sustainability of advanced energy-efficient options.

2.2.4 Case Studies on World's Energy-Efficient Buildings

Residential Buildings

The best energy performing multi-unit residential buildings in developed countries have achieved primary energy consumption of less than 80-100 kWh per m^2 per year with their GHG emission potential limited to 5 tonnes CO_2 equivalent/dwelling/year. They are equipped with air filtration, HVAC systems, air conditioning with dehumidification and on site solar energy (passive or active) generation facilities. Sweden has a housing estate for 1,400 residents, which is a sustainable building complex with 100% renewable energy supply and waste management system with waste utilised as an energy source (B32). Each unit uses no more than 105 kWh per m^2 per year. The best energy consumption in residential buildings in Shanghai in China is 30-40 kWh per m^2 per year with GHG emission of 3.5 t CO_2 e due to low utility consumption. Canada's first Net Zero residential building "Vancouver Home" was commissioned in 2010 (B33). The building has solar energy access and is equipped with natural cross-ventilation, triple glazed windows and visual feedback tools. An open corridor design provides solar energy access to each apartment in the building. It received the LEED-ND certification under neighbourhood development category. In Issaquah, WA, USA,

B29: K.Steyn, G.Siciliano et al., Energy Performance measurement and Verification, Guidance Document from GSEP Energy Management Working Group., August 2014.
B30: ASHRAE Inc., Thermal Performance of Building Envelop Details for Mid and High Rise Buildings (1365-RP), Morrison Hershfield Report No.5085243.01, 6th July (2011)
B31: Continuous Insulation – Green Building, http://smartcisystems.com/products.php
B32: Innovative Buildings, B001 Sustainable Housing Development, Malmo, Sweden, www.cmhc-schl.gc.ca/en/inpr/bude/himu/inbu/upload/B001-sustai.....(2010)
B33: Getting to zero, Comprehensive Approach to Integrated Energy Strategy – Lessons Learned., www.thechallengeseries.ca/chapter-07/net-zero/
B34: Issaquah Highlands., ZHome: The Future of Home Building., www.issaquahhighlands.com/zHome.php (2011)
B35: J.T.Wilkerson, D.Cullenward and D.Davidian, End Use Technology Choice in the National Emerging Modelling Systems (NEMS): An Analysis of the Residential and Commercial Building sectors; www.stanford.edu/-wilkejt1/Documents/End%use use 20% technology (2011)
B36: k.Chmutina and C.Goodier., Making Energy Efficiency and Innovations Pay: An example of Kungsbrohuset Office Building, Stockholm, Sweden., CLUES Innovative International case studies Workshop Series., UCL, London., 2 February 2012.
B37: Green Buildings that Work, A Grander View of the Future: A Case Study of Enermodal Engineering's New Building., A Report (No.613-996-6886) from Public Works and Government Services Canada (PW GSC), 2012.

ZHome is the first fully zero net energy multi-family complex (B34). Its main features include hyper-insulated shell, ground source heat pump and photovoltaic panels.

Commercial Buildings

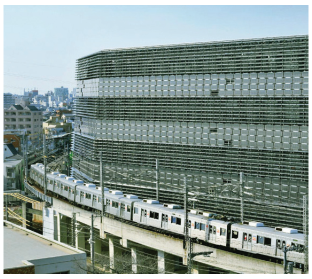
The highly energy-efficient commercial buildings in the world have employed novel control systems, passive, net zero and net positive energy concepts in building envelopes and energy-efficient devices for space conditioning and lighting. Table.2.2.4. highlights the unique features of some of the highly energy-efficient buildings in the world built in the 21st century. The UNDP-GEF has reported the international experiences of promoting energy efficiency in buildings (B69).

Table 2.2.4: Unique Features of World's Energy-efficient Buildings

	Size	Average Energy Consumption kWh/m²/yr.	Special Features
Cascadia Centre for Sustainable Design and Construction, Seattle, USA (2012) Ref: B35	6 Floors 5000 m^2	12*	• High performance envelope • Closed loop geothermal energy input • No PVC, Cd, Pb, Hg and hormone minimisers
Kungsbrohuset Building, Stockholm, Sweden (2010) Ref: B36	13 Floors 39000 m^2	51	• Multi-usage type • Solar thermal heating • Taps heat generated by 200000 people • Intelligent clean tech solutions
Enermodal Engineering Head Office, Ontario, Canada (2009) Ref: B37	3 Floors 2200 m^2	65	• LEED-C1 platinum Certified • Footprint less than 12 meters across • Sandwich walls • Day lighting sensors/controls • Ultra-low plumbing
Tokyo Institute of Technology Environmental Energy Innovation Building, Japan (2012) Ref: B38	9 floors 9,554 m^2	• Entirely energy sufficient • 60+% reduction in CO_2 emissions	• Solar PV/Fuel cell (100 kW) geothermal energy sources • Solar panel envelope (4570 panels of 650 kW) • Desiccant air conditioning using exhaust heat from fuel cell • Cooling/heat pit • Lighting control using day lighting sensor • Clean room and fume food control with motion sensor • Building smart grid system • Seismic energy dissipating outer frame
Paryavaran Bhawan Building, New Delhi, India (2014) Ref: B39	9 Floors 6,000 m^2	• Energy sufficient • Solar power generation: 1.5 million kWh annually;	• Designed to LEED India platinum certification • 930 kW largest roof top solar system • 75% natural day light • 25 year power warranty • Fly ash bricks • Bamboo-jute material for doors
Unwelt Arena, Zurich, Switzerland (2012); Exhibition Centre Ref. B40	7 Floors, 6000 m^2 (165 office workstation for 4000 people)	5.7 • 203% energy self sufficiency • 79 LED moving heads	• 5300 square metres of roof solar PV generation of 540,000 KWh/yr. • Thermo-active Structure • CO_2 neutral during construction/operation

B38: a) Bulletin of the Society of Heating, Air-conditioning and Sanitary Engineering of Japan 88(5), 9-15 (2014)
b) Bulletin of Japan Mechanical & Electrical Consulting Engineering Association 49, 3-10 (2013)
c) Environmental Energy Innovation, Tokyo Tech Challenge: Toward a Safe and Secure Law Carbon Society., www.titech.ac.jp/english/reserach/stories/eei_building html,
B39: Sun power, India's First Green Building Features Sun Power High Efficiency Solar Solution., Presented at 7th Renewable Energy India: Expo, New Delhi (2013)
B40: Sputnik Engineering Participates in the Lighthouse Project Umwelt Arena., Press Release from Solar Max, 4 May (2011)
B69: V.Swarz, Promoting Energy Efficiency in Buildings: Lessons Learned from International Experience, UNDP Report under Global Energy Facility (GEF), New York, USA (2009)

IT IS QUITE FEASIBLE TO CONSTRUCT COMMERCIAL BUILDINGS WITH AN ENERGY INTENSITY IN THE RANGE OF 50–75 KWH/M^2/YEAR AT 2–5% EXTRA COST.



Engineering Lessons Learnt

- The building envelopes with sandwich walls can minimize the loads on HVAC and lighting systems. There is a need to harmonise the building shape to minimize transmission heat losses and to design the passages through the envelope to minimise uncontrolled air leakages.
- There is a need to integrate day-lighting system with the envelope structure. The heating/cooling systems have to maximise the overall energy savings of the buildings. The exterior lighting of the building should not spill off the property boundaries. The daylight zones of buildings must have automatic dimming controls.
- Heating and cooling can be through several smaller capacity heat pumps connected in a loop to facilitate their continuous operation at low speeds. Use of evaporative cooling systems can be preferred in dry climates as well as in cases where higher thermal and latent heat loads are involved.
- Natural ventilation systems have to be preferred for enhanced reliance on stack effect, separation from fenestration and making automatic supply and relief controls independent of occupant interactions.
- There is a need to integrate demand-responsive control systems with energy storage devices, day-lighting and renewable energy generation facilities and use them to reduce peak demand charges and increased load factors.

2.3 Technology and engineering aspects of energy-efficient buildings

It is estimated that the energy intensities of modern residential and commercial buildings in various parts of the world is of the order of 100 KWh/m^2/yr. (B41). It looks quite feasible in future to construct commercial buildings with an energy intensity of no more than 50-75 KWh/m^2/yr. with an extra cost of 2-5%. Fig.2.3.1a highlights the future opportunity areas for engineering of energy-efficient buildings based on passive and active energy and smart approaches. The most important developments will be smart building envelopes and advanced energy management. The smart building market in Asia is expected to grow from US$ 427 to 1036 billion by 2020 creating new opportunities for advanced building technologies and related services. The unprecedented urbanisation rate in this part of the world relies on smart buildings to reduce climate change impact. They will become a major component of smart cities being planned on a large scale in India and China. The CAETS Energy Committee has reviewed and broadly analysed the technology and engineering developments related to energy-efficient building constituents in recent years. The committee has identified the high impact making building envelopes, HVAC systems and advanced management systems for a technology review presented in Sections 2.3.3 to 2.3.5.

2.3.1 Challenges of Retrofit Engineering

Retrofitting the existing building along with new building improvement worldwide holds the key to a low emission building sector from 2030 and beyond. This is evident from the GHG emission projections made by the International Council of Chemical Association (ICCA) for EU, Japan and USA for 2000 to 2050 employing scenario-based modelling with building renovation and retrofitting as the focus areas (B17). The details are in Fig.2.3.1b. It shows that even as floor area in these countries increases from 59 to 93 billion m^2 during 2000-50, the GHG emissions can be brought down to 60-65% of that recorded in 2000 through new building improvement, ambitious retrofitting and LC fuel switching.

The building retrofit engineering has to consider the extreme diversity of existing buildings from all standpoints viz., period of construction, material quality, construction methods and category of usage. Engineers have to make difficult trade-offs in the degree of retrofitting to achieve techno-economic attractiveness at local level. Conducting structural, engineering

B41: L.D.D.Harvey., Recent Advances in Sustainable Buildings: Review of Energy and Cost Performance of the State of Art Best Practices from Around the World., Ann.Rev. Environ.Resource 38, 281-309 (2013)
B17: ICCA Building Technology Roadmap, International Council of Chemical Associations (ICCA), Brussels, Belgium (2010)

EXTREME DIVERSITY OF EXISTING BUILDINGS IN TERMS OF CONSTRUCTION PERIOD AND METHODS, MATERIAL QUALITY AND NATURE OF USE MAKE THE TRADE OFFS IN RETROFITTING QUITE CHALLENGING.

Fig.2.3.1a: Engineering Options for Energy-efficient Buildings

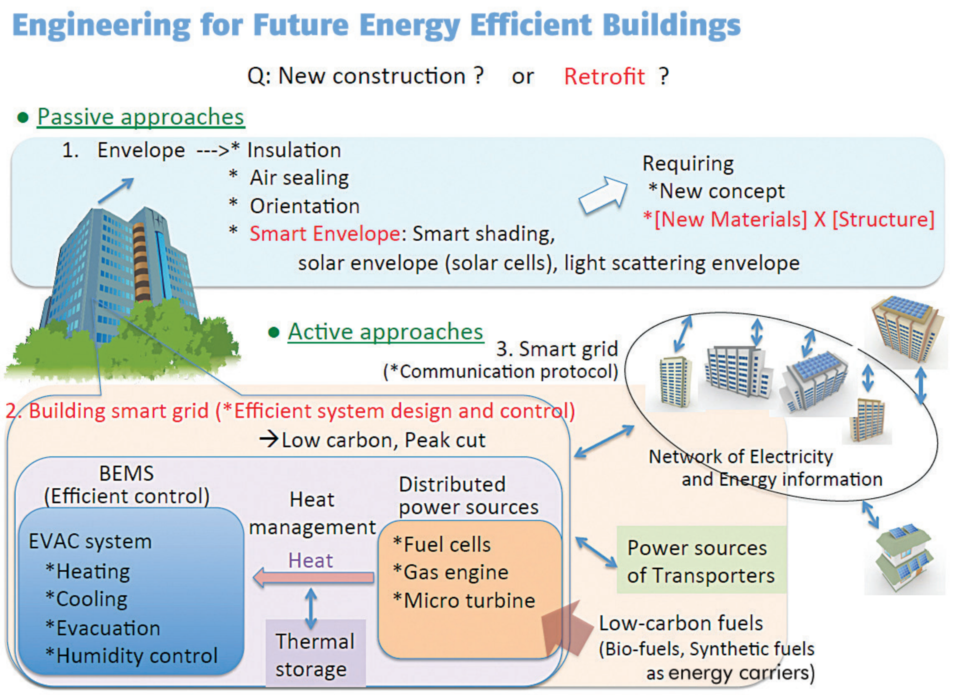
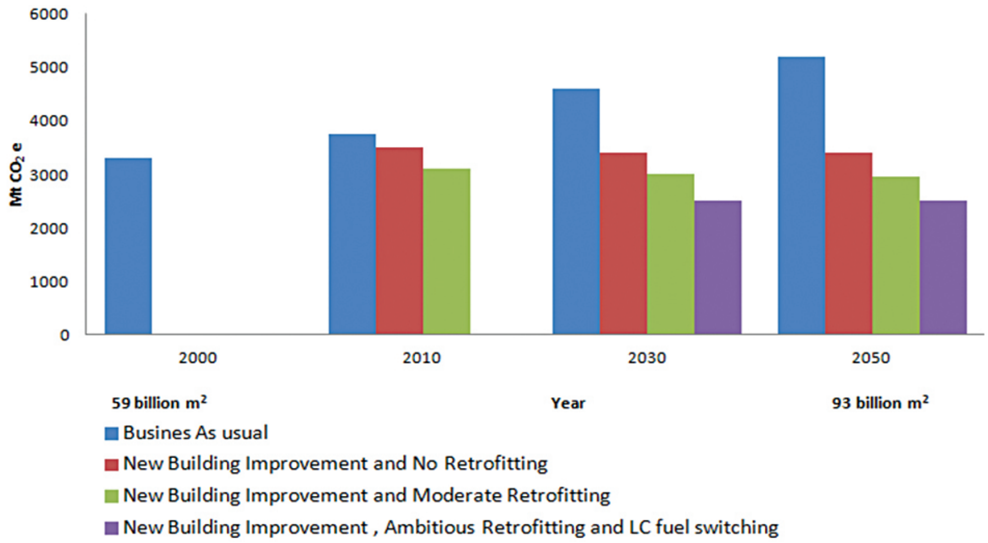


Fig.2.3.1b: GHG Emission Reduction Scenarios for EU, Japan and USA Building Sector



ENGINEERING OF ENERGY EFFICIENT "DEEP RETROFITS" IS MUCH MORE CHALLENGING THAN THAT OF "SHALLOW RETROFITS"

and energy audits covering facade orientation, shading of neighbourhood, wall structure, insulation and ventilation needs and energy consumption and wastages is the major task. Design calculations for building envelope and HVAC systems have to follow. Use of modelling and simulation tools to assess the impact of proposed retrofitting on complex building structures requires specialised knowledge.

Engineering of energy-efficient "deep retrofits" is more challenging than "shallow retrofits". They would dominate the scene for most parts of the 21st century, since they can reduce existing building energy consumption by 50-75%. The deep retrofitting covers several aspects: air and water infiltration minimisation; mitigating radiative thermal effects; introducing thermal breaks to minimise thermal bridging in building envelopes; improved duct and piping layouts; reduction of heating and cooling loads and replacing the existing HVAC facilities with high peak and part load efficient equipment; use of variable speed drives for compressors and

SOLAR PHOTO VOLTAIC RETROFITS WILL BE MORE WIDELY USED IN FUTURE AS THEIR COSTS DROP TO ACCEPTABLE LEVELS

MORE THAN 400 SOFTWARE TOOLS BASED ON CONSTELLATION OF MODELS, NUMEROUS DATA BASES AND SYSTEM ANALYSIS TOOLS CAN BE EMPLOYED FOR SIMULATING THE ENERGY PERFORMANCE OF BUILDINGS.

improved air and water distribution systems; and improving efficiency of utility generation systems (B42).

Energy intensities of less than 40 KWH/m²/Yr. are achievable with an incremental cost of 0.1-0.45 US$/KWh. The IPCC reported (B2) light retro-commissioning cases involving significant energy savings (50-75%) with extra investment costs ranging from 53 to 760 US$ per square metre of building area for high-rise buildings and individual and multifamily housing units. It also reported 21 retrofit cases of household appliances covering air conditioners, refrigerators, fans, ovens, dryers, lighting, etc., with potential reduction (40-50%) in unit energy consumption. The Empire State building in USA is an icon of energy-efficient deep retrofitting in the world. During 2011-14, it enabled to save US$ 7.5 million in energy costs. There are new opportunities for the incorporation of alternative energy systems as retrofits into the existing buildings. Solar photovoltaic retrofits will be more widely used in the future as their unit costs drop below the commercially acceptable levels (B43). In USA alone, around 50,000 geothermal heat pump retrofits are installed (B44). From an economic perspective, building retrofits can generate larger annual cost savings to make them economically attractive eventhough they generally entail a higher upfront cost. Shallow retrofits normally lead to greater life cycle costs than deep retrofits.

2.3.2 Simulating the Energy Performance of Buildings

More than 400 software tools have been reported for evaluating the energy efficiency and application potential of renewable energy (B45&46). They are in the form of databases, spreadsheets, component system analysis tools, and whole building energy performance evaluation systems. The overall performance of buildings can be analysed with a constellation of models (B47). The day lighting models specify daylight redirection devices, reflective room surface finishes and efficient artificial lighting. Sub-models are available to evaluate airflow patterns and thermal exchange associated with solar collectors and photovoltaic systems. The performance of window configuration and control systems for natural ventilation are evaluated by explicit modelling of the concerned mass thermal effects. The performance of electric heat pumps, combined heat and power systems (micro, biomass or fuel cell based) and thermal storage devices can be simulated. The CAETS Energy Committee recommends the engineers to employ modelling approach on a much wider scale for simulating the energy performance of large residential complexes and commercial buildings with complex structures to generate vital preconstruction information for new constructions as well as for deep retrofits.

2.3.3 Energy-efficient Building Envelopes and their Retrofits

Nearly 2 billion new buildings are likely to be constructed worldwide by 2050 with an estimated floor area of 255 billion m² (90% residential and 10% commercial). They are reported to cost around US$ 3.7 trillion to achieve an energy savings of 6.5 exajoules per annum (77% residential) and emission reduction to the extent of 525 Mt CO_2 per annum. The energy-efficient building envelopes will, therefore, play a major role in achieving energy and emission reduction in the global building sector.

Technologically, the envelope refers to the shell of a building which acts as a barrier to unwanted heat and mass transfer between its interior and the external environment. Its effectiveness depends on the insulation level, the thermal properties of windows and doors and rate of air exchanges between interior and exterior. Improvements in the design of the thermal envelope can bring down the building heating energy by a factor

B42: H.C.Foley., Challenges and opportunities in engineered retrofits of buildings for Improved Engineering Efficiency and habitability. AIChE J 58(3), 658-667(2012)
B43: H Wirth, Recent Facts about Photovoltaics in Germany, A Report from Fraunhofer ISE, Germany, 28 July (2014)
B44: Geothermal Heat Pumps., http://energy.gov/energysaver/articles/geothermal heat pumps, US DOE, Washington (2012)
B45: A.Hirsch, S.Pless, R.Guglielmetti and P.A.Torcellini., The Role of Modelling when Designing of Absolute Energy Use Intensity Requirement in a Design – Build Framework., Paper presented at ASHRAE Winter Conference, Las Vegas, USA (2011)
B46: Building Energy Software Tools Directory. http://www.eere.energy.gov/buildings/tools_directory/
B47: A.Aksamija, Building Simulations and High Performance Buildings Research: Use of Building Information Modelling (BIM) for Integrated Design and Analysis, Perkins+Will Research Journal, 5(01), 20-34 (2013)

of two or more at a fraction of the total building cost. Envelope design is a highly specialised and challenging architectural and engineering practice particularly in case of large building complexes (B48). Comprehensive building envelope design guides, 3D spatio-thermal modelling tools, dimensioning tables for insulation selection, their finite element thermal modelling and efficiency analysis are employed by engineers for their design (B49 to B54). The typical engineering parameters relevant to energy-efficient building envelopes are shown in Table 2.3.3.

OUTSTANDING SUCCESS IN PASSIVE, NET ZERO AND NET POSITIVE ENERGY EFFICIENCIES IN COMMERCIAL BUILDINGS HAVE BEEN REPORTED

Table: 2.3.3 Typical Engineering Parameters for Energy-efficient Buildings

No	Item	Engineering Specifications
1	Overall energy use	Less than 75 kWh per m^2 of floor area per annum
2	Overall heat transfer coefficients, W/ m^2.K	01-0.3 for walls 0.7 – 1.4 for windows
3	Air tightness, l/s.m^2	0.2-0.3
4	Window to wall ratios, %:	12-36
5	Space Utilisation efficiency, m^2/person	12-20
6	Light energy consumption, W/m^2	10-12
7	Automated lighting system norms - Illumination levels, lux - Maximum Switch on time, hrs/day	 300-500 8-10
8	Type of ventilation systems employed	Constant and variable air volumes, hybrids and night varieties

The CAETS Energy Committee acknowledges the outstanding successes reported in recent years in achieving passive, net zero and net positive energy efficiencies in new commercial buildings in several countries. It is more energy-efficient in cold climates to access both heat and light from solar resources; whereas in hot climate, one can access solar light but heat has to be converted into cold. The countries that experience hot and humid climates are primarily developing economies and they are experiencing massive growth of new building construction. The CAETS Energy Committee underlines the urgent need to develop innovative technology options for them, which are cost effective and based on frugal engineering concepts.

SMART MATERIAL DEVELOPMENT THROUGH MOLECULAR MODELLING IS STILL FAR AWAY FROM REALITY IN SPITE OF SEVERAL ENABLING TECHNOLOGIES DEVELOPING FAST.

New energy-efficient building envelopes require green facade, advanced air sealing and insulation, low conductive windows, and advanced roof and wall for cold climates. Several technological and engineering options are available: sealed and openable inner and outer skin type facades, high performance cellulose, fibre glass and closed cell spray PU foams for insulation, vapour retarders, air barriers and rain screens for air sealing, low emission/conductive windows with electrochromic solar control glazing and advanced roofing systems with reflective surfaces, reinforced liquid membranes and thermos plastic polyolefin. Development of sustainable building material and construction for energy-efficient building envelopes deserves special attention (B55). The next generation materials will be in the form of vacuum insulation panels, water resistant membranes for building facades, intelligent membranes for air leakage minimization and silica fibre felt modified with titanium dioxide for odour control.

Smart Building Envelopes

The CAETS Energy Committee sees the potential of using smart technologies to reduce excessive energy and environmental loads in building envelopes. Glass, which is used to accentuate light

B48: S.Asif, Advanced Building Technologies for Sustainability, John Wiley & Sons Inc., 115 pp (2012)

B49: D.J. Lemieux and P.E.Totten, Building Envelope Design Guide – Wall Systems, Wiss, Janney Elstner Associates Inc., (2010)

B50: Y.Ham and M.G.Fard., Rapid 3D Energy Performance Modelling of Existing Buildings using Thermal and Digital Imagery., Construction Research Congress (SCE-2012), 991-1000 (2012)

B51: Dow Corning., High Performance Insulation for Next Generation Curtain Walls, www.dowcorning.com/content/published list/62-1722-01.pdf

B52: F.S.Westphal, M.Yamakawa adn L.T.Decastro., Thermal Insulation of Building Envelope toward Zero Energy Design in Hot Humid Climate, Proceedings of Building Simulation: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 December (2011)

B53: P.Parker and C.Lozinsky, Thermal and Hygrothermal Analysis in Building Envelope Commissioning, Best 2-Inherent Risk of Going Green – Session WB 3.3 (2010)

B54: Principles of Heating, Ventilating and Air-conditioning, ASHRAE Hand Book – Fundamentals, 7th Edition, 600 PP (2013)

B55: a) Certain Teed., Sustainable Products and Systems: A Reference for Building Responsibilities, A Report from Saint Gobain; www.certainteed.com/resources/Green_corporate-Green-Brochure.pdf

b) A.Tanikella and V.Natarajan, Sustainable Building Materials for Energy Efficiency and Multicomfort (Private Communication)

and space, is the most susceptible to high amount of energy loss. Smart technologies will stimulate the continued use of glass for building envelopes. It is possible to design the micro and macro structures of smart materials, which undergo property changes with input of energy, to provide the required chemical reactivity, heat density, and optical and acoustical characteristics.

The emerging smart envelope options are based on the following;

- Suspended particle device technologies for electronic control of light and heat transmission through glass windows (B56)
- Phase change materials in reinforced aluminium envelope skin (B57)
- Energy producing algal facades to harvest the solar heat and store in the building
- Titanium dioxide coating to glass to effectively scrub the air of toxins.
- Sunscreens that can deflect the unwanted glare in glass facades (B64),
- Thermal metal screens which can curl up when the surface is hot (B58) and
- Temperature responsive and shape memory polymers to react to stimuli and environmental changes are recent developments.

The combination of smart materials and nanotechnology provides new opportunities for enabling building envelopes to behave similar to human skin to thermal responses (B59). The CAETS Energy Committee considers the engineering development of smart materials at atomic scale is still far away. However, there is rapid development of the enabling technologies.

GLOBALLY, AN ESTIMATED 14 BILLION M² OF EXISTING BUILDING SPACE IS EXPECTED TO BE RETROFITTED OVER THE NEXT 30 YEARS.

Solar Envelopes

Solar envelopes are independent building envelopes with solar cells. They generate electricity and reduce the cooling load by shading effect. They geometrically define the sunlight that buildings may own. They have independent structure from that of the main building. There is Insulation in the space between them and the building walls. They are conditioned in space as well as time. Their size and shape vary round the year. They are designed for four hours of sunshine in winter and eight hours in summer. Their size, shape and orientation greatly influence the street patterns (B60). Their growth depends on the public policies guaranteeing access to sunshine. From an engineering perspective, their designs are governed by the solar access and iso-solar surface concept developed by Ralph Knowles in 1960s (B61). An engineering method has been reported very recently (B62) for the design of compact urban housing based on solar envelope concept.

Energy-efficient Envelope Retrofits

Energy-efficient retrofits provide post-construction opportunity to engineers to introduce moderate as well as deep energy improvement. It is estimated that about 14 billion m² of existing building space would be renovated across the world over the next 30 years. The existing level of retrofitting is not more than 2.2% per annum. This is mainly due to a wide array of technological, regulatory and administrative challenges faced by the building sector. Energy-efficient envelope retrofits are available under roof, wall, window and basement categories. Several engineering options are available for their implementation. They employ air barriers, foam insulation, reflective coating, high performance panelling, and fenestration and spray foam technologies. Radiant slab cooling technology, in which cold-water flows through pipes embedded in roof slabs for cooling them to 20°C has been used for the first time in India by INFOSYS for its office building (24,000 square meters) at Bengaluru. The technology is a retrofit option (B63). There is a strong need for professional engineers to understand the structure-retrofit interactions more precisely to devise such cost-effective systems.

B56: M.Beevor, Smart Building Envelopes, A Report from University of Cambridge, UK, June (2010).

B57: A.A.Chernousov and B.Y.B.Chan., Thermal Characterization of Smart and Large Scale Building Envelope System in a Subtropical Climate, International J.Civil, Structural, Construction and Architectural Engg 9(4), 336-340 (2015)

B58: K.Campbell, 5 Smart Building Skins that Breathe, Farm Energy and Gobble up Toxins, A Report by Gizmodo, 9 May (2013)

B59: Pongratz Perbalini Architects., Smart Materials and Building Envelopes F10, Google Report, 2 November (2010)

B60: R.L.Knowlers., The Solar Envelope: It's Meaning for Energy and Buildings, Energy and Buildings 35, 15-25 (2003)

B61: E.Morello and C.Ratti, Sunscapes: Solar Envelopes and the Analysis of Urban DEMS, Computers, Environment and Urban System. 33(1), 26-34 (2009).

B62: A Vartholomaios, The Residential Solar Block Envelope: A Method for Enabling the Development of Compact Urban Block with High Passive Solar Potential, Energy and Buildings 99, 302-312 (2015)

B63: G.Sastry, First Radiant Cooled Commercial Building in India – Critical Analysis of. Engg. Comfort and Cost, www.aeecenter.org/files/newletters/ESMS sastry.pdf (2013)

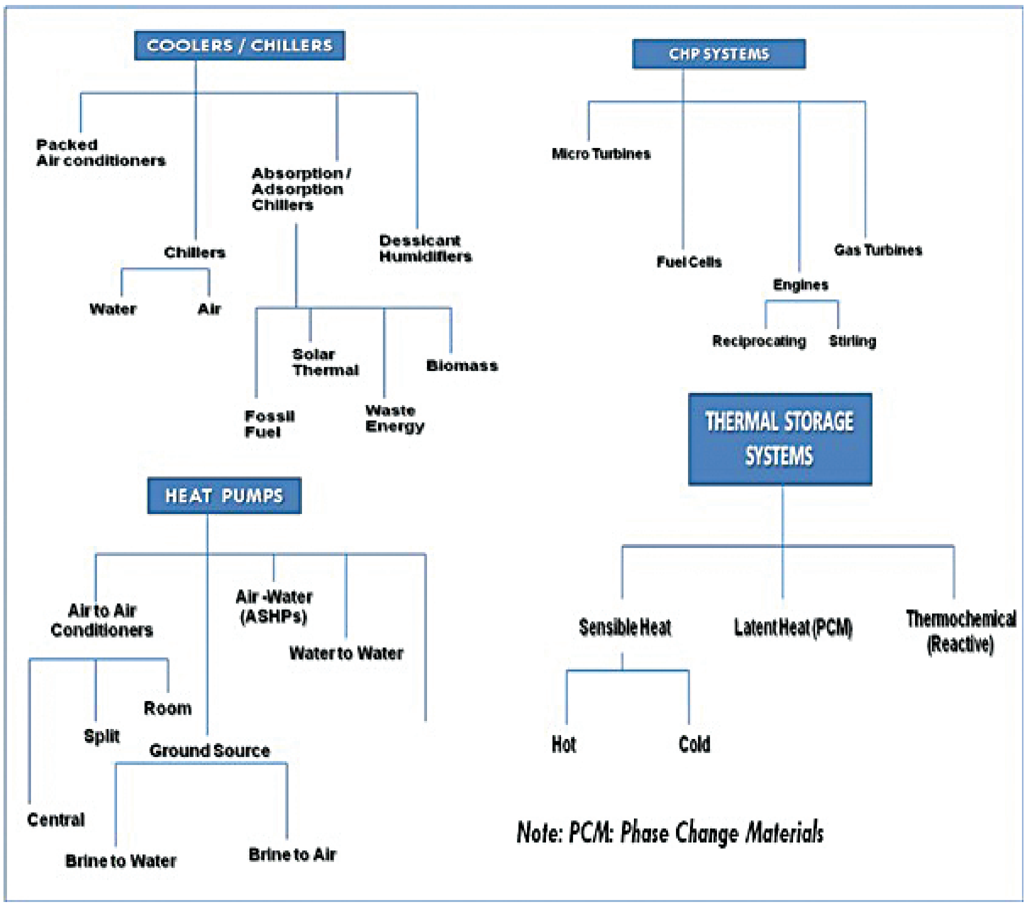
2.3.4 Energy-efficient HVAC Systems and their Retrofits

The heating, ventilation and air-conditioning (HVAC) systems account for 30-35% of energy used in the buildings. The use of energy-efficient HVAC units can reduce this consumption by 30% with a payback of 3-5 years. The CAETS Energy Committee shortlisted those for technology review considering their attractive energy saving potential and the rapid technological and engineering advances to improve their performance. From an engineering perspective, three important HVAC components need attention viz., heating/cooling, ventilation and air conditioning. A fixed amount of a heat transfer medium is circulated at a sufficiently hot or cold temperature to effect heating/cooling. The ventilation system maintains an acceptable non-odorous atmosphere and CO_2 levels in the building through air handling units. The air-conditioning systems treat the air inside for achieving an acceptable temperature, humidity and purity by heat pumping. Fig.2.3.4 highlights the various options available for HVAC units.

THERMAL ENERGY LOAD TO HVAC UNITS PRIMARILY COMES FROM BUILDING ENVELOPES, LIGHTING, OCCUPANTS, VENTILATION AND OTHER EQUIPMENTS. MOST OF THE CURRENT HVAC UNITS ARE GROSSLY OVER DESIGNED DUE TO HIGH FACTOR OF SAFETY.

ASHRAE Handbook on HVAC systems (B54) provides load calculation spreadsheets and engineering information on fenestration components. There are several simulation packages viz., DOE-2, ENERGY PLUS, ESP, DeST and FCU. They contain component models including those for pumps, cooling coils, cooling towers, fans, chillers and boilers. Virtual simulation capabilities can speed up the design process (B64). Air-to-water heat pumps, often called air source heat pumps (ASHP) can avoid expensive ground or water loops for residential hot water and space heating. Water-to-water and water-to-air heat pumps take advantage of an available water source as the heat source or sink and are typically more efficient than ASHPs. At present, the coefficient of performance (COP) of these devices lies between 3.5 and 5. There may be a further increase

Fig. 2.3.4: Various Options for Heat Pumps, Coolers, CHP and Thermal Storage Systems



B54: Principles of Heating, Ventilating and Air-conditioning., ASHRAE Hand Book – Fundamentals, 7th Edition, 600 PP (2013)
B64: ANSYS, HVAC Equipment Design, www.ansys.com/industries/construction/HVAC+Equipment+Design (2014)

THE COEFFICIENT OF PERFORMANCE OF HEAT PUMPS LIES BETWEEN 3.5 AND 5

THERE ARE THREE MAJOR TYPES OF THERMAL ENERGY STORAGE SYSTEMS VIZ., SENSIBLE HEAT, LATENT HEAT AND THERMOCHEMICAL SYSTEMS.

in COP (20 to 50%) and reduction in installed cost (5 to 30%) by 2030. The installed cost of heat pumps for single-family dwellings is from US$350-650/kW. Two-speed compressors allow heat pumps to operate close to the heating or cooling capacity needed at any particular moment. This saves large amounts of electrical energy. Many high-efficiency heat pumps are equipped with a desuperheater, which recovers waste heat from the heat pump's cooling mode. They can heat water 2 to 3 times more efficiently than an ordinary electric water heater. Other developments in heat pump technology is the use of scroll compressor with a longer operating life (B65) and thermal-driven absorption heat pumps which work at three different temperature levels (B66). The latter can be operated both in heating and cooling modes.

Solar Heating/Cooling Systems

Solar thermal technologies provide heat that can be used for low-temperature heat application in buildings, for water and space heating and cooling with thermally driven chillers (B67). Current solar water heating systems for single-family dwellings are relatively small with collector areas of up to 6 m^2 and meet 20% to 70% of hot water needs with 150 to 300 litre storage tank. Solar systems for multi-family dwellings, which provide space and water heating are larger with current systems having an area of around 15 m^2 with a 1000 to 3000 litres storage tank.

Combined Heat and Power Systems

The Combined heat and power systems (CHPs) provide electricity and heat for space/water heating. They are coupled with thermally driven chillers, sometimes referred to as tri-generation systems. There are several mature CHP technologies, employing reciprocating engines and turbines. Newer CHP technologies are based on Sterling engines, fuel cells and mini-CHP units. They are not yet fully commercialised. Typical CHP operational efficiencies are from 75% to 85% with state-of-the-art plants achieving efficiencies up to 90%. The CHP capacities for single-family dwellings are available from one to 10 kW while 30 to 500 kW capacities are available for multifamily dwellings. For commercial buildings, five MW systems are available. The CHP systems can also harness waste thermal energy to drive absorption chillers or desiccant dehumidification systems. Micro gas turbines are also now used in small and medium scale CHP systems. They operate at very high speeds and employ electric power inverters to work in parallel with electric power systems. They achieve electrical efficiencies of 5 to 30%, and operational efficiencies of 65% to 70% at an installed cost of US$2/W.

Fuel Cells

Fuel cells can offer nearly 1-to-1 electricity-to-heat ratios making them well suited for modern low-energy buildings. Small-scale fuel cells range from one to 100 kW, with efficiencies of 75% and installed cost of US$ 8/W, whereas large-scale fuel cells of 2.5 MW capacities with efficiencies up to 80% are available at a cost of US$ 5/W.

Thermal Storage

There are three major types of thermal energy storage systems viz., sensible heat, latent heat and thermochemical systems. Current engineering R&D is focused on reducing the specific costs of high-density storage systems whose costs are still too high for many applications in buildings.

The CAETS Energy Committee has noted the energy load to a HVAC system primarily comes from thermal envelope, lighting, occupancy level, ventilation and equipment from programmed use. Energy-efficient HVAC units need high quality design engineering inputs. The Committee has also noted that due to high factor of safety adopted, most of the currently used HVAC systems are over-designed. They need to be re-designed as per scientifically evaluated peak heating/cooling loads. This measure will contribute to the first level energy savings. Part load performance has to be a critical factor for sizing variable capacity HVAC units. Thermal energy storage system is an important facilitating technology for energy-efficient HVAC systems.

B65: Heat Pump Systems, http://energy.gov/energysaver/articles/heat-pump-systems, US DOE, Washington (2013)
B66: A.Kuhn, Thermally Driven Heat Pumps for Heating and Cooling, Report with ISBN (online) 978-3-7983-2596-8 published by the Technical University Berlin (2013)
B67: IEA, Technology Roadmap – Energy-efficient Buildings: Heating and Cooling Equipment, International Energy Agency (2011)

ACHIEVING IMPROVED PART LOAD EFFICIENCIES IN HVAC UNITS IS VITAL SINCE CURRENTLY MOST OF THEM OPERATE AT FULL LOAD FOR LESS THAN 5% OF THEIR RUN TIME.

CONCEPT OF INTELLIGENT AND SMART BUILDINGS IS CATCHING UP FAST IN INDUSTRIALLY ADVANCED COUNTRIES.

One or more of the following modern technological options can help reduce mechanical HVAC demands anywhere from 10 to 50%:

- Condensing boilers with lower carbon fuels
- Water to geothermal heat pumps
- Active solar thermal systems
- Chillers with efficient condensers, compressors and controls
- Displacement ventilation/ variable speed fans and demand controls
- Radiant chilled beam ceiling
- Water-based cooling towers for dry climates
- Modulating controls for burners and compressors
- Cromer cycle driven dehumidifiers
- Advanced roof top and ductless mini-split air conditioners with improved part load efficiencies
- Intelligent HVAC controls tracking occupant levels, season and time of the day

HVAC Retrofits

The CAETS Energy Committee has examined the various technical issues relevant to HVAC retrofitting. The committee is of the opinion that a HVAC retrofit has to take advantage of newly emerging technologies. Replacing less efficient HVAC equipment with more efficient ones has the potential to cut energy costs by 20%. Considering the environment angle, the underlying technologies have to be so selected that better filtration of NOx, CO, SOx and other pollutants becomes possible. Operational flexibility has to be another important factor in retrofit selection. Achieving a better part load efficiency should be a major engineering factor for HVAC equipment since most of them operate a full load for less than 5% of their total run time. Systems approach is best suited for HVAC retrofitting since it accounts for interaction between them and the different building components and favours reduced peak loads for individual HVAC units. It is essential to carry out energy audit of various subsystems by using a set of diagnostic tools and field studies of best practices. Appropriate HVAC models can simulate the overall building energy performance.

The typical technological options for retrofitting to make the existing systems more energy-efficient are:

- Coupling solar thermal collectors with chillers
- Use of multispeed heating/cooling devices
- Coupling energy economisers to ventilation
- Zoning of buildings to enhance occupant comfort levels
- Variable frequency drives for fans and compressors
- Interoperable building automation

2.3.5 Advanced Energy Management Systems (AEMS) and their Upgrades

The concept of intelligent and smart buildings is catching up fast in industrially advanced countries. Around 20% of their commercial buildings have already been equipped with digital energy management systems. The global AEMS market is poised to reach US$ 5.6 billion by 2020 from the present level of US$ 2 billion. Realising AEMS's potential to introduce new knowledge and intelligence in energy efficiency management in building sector, the CAETS Energy Committee has shortlisted it for technology review process.

The AEMS consists of centralised, interlinked and networked systems with necessary hardware and software to monitor and control the environment in building complexes. The AEMS controls, mechanised, electrical and utility service units including HVAC, boilers, chillers, air handling units, heat pumps, lighting, power sources, access control and fire alarm systems. From engineering perspective, early versions of AEMS were equipped with pneumatic and air-based control systems predominantly tailored for HVAC units. Analogue electronic control devices were introduced in 1980s. The direct digital control (DDC) concept was used with proprietary communication methods. In case of intelligent buildings, computer aided management tools and sensors supported by UNIX, LINUX and WINDOWS based hardware/ software and wireless technology are used. A new era of AEMS will soon dawn on the

SCALING UP OF ENERGY EFFICIENCY IN BUILDINGS NEED A THREE PRONGED APPROACH VIZ., PILOTING FOR TECHNOLOGY PROVING, PREPARING THE STAKEHOLDERS TO EMBARK ON APPROPRIATE RETROFITTING AND ADOPTING ENERGY OPTIMIZATION OF ENTIRE BUILDING.

building sector with the entry of energy analytics to quickly analyse and control energy costs through real-time visualisation of multiple energy scenarios. Their interfacing with smart grids will soon become a reality. Cloud-based building energy management is on the cards with the expansive ability to handle big data from several building complexes. Smart phones, bluetooth devices, tablets and other personalised interfaces will enable introduction of a variety of novel user options as required by the smart buildings.

The upgradation of existing AEMS is a highly challenging engineering task since most of the existing control systems employ stand alone concepts with separate monitoring and control stations. Preparation of detailed engineering package for upgradation of existing AEMS is an absolute necessity. Many influencing factors need balancing while selecting new AEMS equipment. The CAETS Energy Committee considers the technological upgradation of existing AEMS as difficult with doubtful outcomes in some cases. There is need for more engineering advances to evolve intelligent AEMS upgradation technologies.

Smart Building – Electricity Grid Networking

Smart electricity grids employ information and communication technologies very effectively to access information from a large number of suppliers and consumers in an automated way. This will facilitate energy integration from intermittent renewable resources more effectively and distribute the electric power very efficiently to the innumerable consumers. The real value of a smart grid can be unlocked only with smart buildings which represent the convergence of building controls technology and information management. Smart energy-efficient buildings can leverage virtual knowledge from the smart grids to achieve real time high performance levels. The CAETS Energy Committee foresees the building and smart grid link up will become a key engineering activity in the coming years. The HVAC systems and their controls, lighting and safety systems can be linked to smart power grids endowed with time variant demand and supply responses, which are occupancy, weather and end user dependent. It is estimated that by 2030, US$ 30 billion can be saved annually with the large sized smart commercial building systems with emission reduction of 340 mega tonnes of CO_2 annually. When extended to medium-scale residential and commercial buildings, there can be a further energy savings of 10-30%.

The CAETS Energy Committee is of the opinion that the introduction of smart technologies into the building sector will be a medium-term option. It has the potential to improve electrical grid efficiency quite significantly and the supply/demand balance may reduce the need for back-up energy generators. The smart grids will provide new opportunities for the control engineers to develop smart sensors and meters required by the energy distribution segment, energy resource sites and at building sites with their own unique supply-demand responses. This technology will play an important role in the deployment of smart electricity infrastructure in developing countries with high industrial growth prospects such as China, India, Brazil and South Africa.

2.3.6 Global Experiences in Scaling up Energy Efficiency in Buildings

The CAETS Energy Committee reviewed the reported global experiences on scaling up energy efficiency in buildings (B69 to B71) in developed and developing countries. The following have significant effect on major technological and engineering interventions in residential and commercial buildings worldwide.

- Energy efficiency technologies require multipronged implementation approaches supported by proven techno-economics, mix of policy tools and enabling market environment.
- Pilot energy-efficient building technologies will facilitate technology evolution over time in developing economics for incremental introduction of complex technological options.

B69: V.Swarz, Promoting Energy Efficiency in Buildings: Lessons Learned from International Experience, UNDP Report under Global Energy Facility (GEF), New York, USA (2009)
B70: ESMAP, Western Balkans: Scaling up Energy Efficiency in Buildings, Final Report by the World Bank Group to ECSSD and ECA (2014)
B71: F.Liu, A.S.Meyer and J Hogan, Mainstream Building Energy Efficiency Codes in Developing Countries: Global Experiences and Lessons from Early Adapters, World Bank Publication (2010)

THE INVESTMENTS MADE ON ENERGY EFFICIENCY IMPROVEMENT INITIATIVES AVOID MORE THAN DOUBLE THE CAPITAL INVESTMENT NEEDED TO CREATE ADDITIONAL ENERGY GENERATORS.

GHG EMISSION ABATEMENT COST OF BUILDING SECTOR IS AROUND USD 36.5 PER TONNE CO_2e

- Propagation of technologies relevant to deep retrofits requires preparing diverse set of stakeholders including research groups, policy makers and large cross-section of building owners with the help of audits of energy use.
- Mandatory energy standards for building components and equipments provide the first step towards making buildings energy-efficient since they have shorter life span than the envelopes.
- Multiple technological and engineering options are available for decarbonisation of existing fossil fuels, energy-efficient building designs, material selection and HVAC and other equipment replacement. There can be significant savings by scientifically optimising the energy systems in the entire commercial building complexes rather than improving its individual elements at a time.

2.3.7 Cost Effectiveness of Energy-efficient Buildings and their Growth Prospects

Investment made on energy efficiency initiatives avoids more than double the investment needed for creating additional energy generation facilities. The building sector has a very large number of end uses employing multiplicity of technologies and engineering equipments. The engineering challenges lie in prioritising their applicability, ensuring their techno economic feasibility and assessing their retrofit dynamics. McKinsey & Co., (B13) estimated the average GHG emission abatement cost of building sector is around US$ 36.5 per t CO_2 e with total upfront capital investment worldwide of US$ 225 billion per year and operating expenditure of US$ 270 billion per year in 2030. The CAETS Energy Committee is of the opinion that this level of global investment may be within the lending capacity of building financial markets, which are consumer driven. Indeed many of the future opportunities would see energy savings largely compensate for upfront investments.

The IPCC (B2) reported that the cost effectiveness of energy efficient buildings during the last decade has not diminished in spite of continuously improving energy standards. There is increasing evidence that energy-efficient building construction is possible with marginal cost escalation. Implementation of passive energy concept for new buildings is possible practically at the same cost as a building constructed strictly as per local energy codes. However, zero net energy buildings are not cost effective by conventional standards. They need incentives to enhance their techno-economic feasibility. The cost effectiveness of shallow retrofits with energy reduction by 10-30% is quite attractive. Deep retrofits with 50% or more energy reduction can be cost effective in specific climates, buildings and cultures. Retrofits, getting closer to 100% savings will be expensive due to the use of costly materials and devices and building integrated renewable energy generation technologies.

Governments worldwide are introducing new policies, market incentives, prescriptive measures and regulations to optimise energy use in buildings. Many energy efficiency projects are feasible at US$ 60 per barrel oil price. The global market for energy-efficient buildings, products and services is reported to grow from US$ 307 billion in 2014 to US$ 623 billion in 2023 (B68). During transition to LCE, the development of energy-efficient buildings presents both risks and opportunities for companies seeking to enter this market. There are potential first mover advantages for agencies entering the energy efficiency market. Subsequent competitors may face entry barriers in the form of specialist knowhow. For replication of energy-efficient buildings on a large scale requires innovative policies and regulations at national level to ensure that the right conditions are in place and make energy in buildings more valued than what it is today.

2.3.8 Low Cost Energy-efficient Buildings for Developing Economies

Low cost energy-efficient buildings are of high priority not only in developing economies but also for low-income groups in developed

B2: O.Lucon and D.U.Vorsatz., Buildings: Climate Change 2014: Mitigation of Climate Change. Chapter 9 of 5th Assessment Report (ARC) of IPCC, Cambridge, UK and USA (2014)
B13: McKinsey and Co., Pathways to a Low Carbon Economy: - Version 2 of the Global Greenhouse Gas Abatement Cost Curve. A Report from McKinsey & Co., (2009)
B68: Navigant Research, Energy-efficient Buildings: Global Outlook, A Report on Global Market Analysis and Forecasts, 88 pages (2014)

THE DEVELOPMENT OF ENERGY-EFFICIENT BUILDINGS AT LOW COST FOR DEVELOPING ECONOMIES REQUIRES WISE INVESTMENT DECISIONS TO BALANCE EFFICIENCY OUTCOMES WITH IMPLEMENTATION COSTS DRIVEN BY FRUGAL ENGINEERING CONCEPTS AS AN OVERARCHING PHILOSOPHY.

countries. They have to be optimally designed for low energy use and operating and construction costs. A need also exists for low cost energy retrofits. Low cost systems require wise investments that can balance efficiency outcomes with initial costs. The main challenge is not only in evolving novel designs relevant to local environment but also in taking sound trade-off decisions based on cost and outcomes. An interesting example is the housing project developed by the Indian Institute of Technology (IIT), Madras, India for low-income group families. The project used prefabricated glass fibre reinforced gypsum panels employed earlier in Australia and the apartment costs less than US$ 20 per square metre. The passive solar building design is a priority area for low cost housing to achieve maximum solar gain in walls, ceilings and floors. Appropriate building construction techniques are required to achieve environmentally stable and resource efficient systems. The design need to take proper account of climate, human comfort and other factors.

In several parts of the world, it has become possible to replace traditional buildings with low cost energy efficient ones. Uninsulated walls have been replaced with thin insulated walls and roofing, double glazed windows with single glazed low emittance systems, manual exhaust with mechanical exhaust systems with space heating pumps, electrical resistance heating with heat pumps from exhaust oils and use of imaging reflectors, ballasts and simple controls for fluorescent lighting. One can also promote motorised dampers for air-conditioning systems, rezoning of HVAC systems and better management of energy and local building material in low cost building systems. Low cost energy upgrades are often the best way to get started during the transition phase.

Frugal engineering is an overarching philosophy that enables a simpler approach to product development. Cost discipline is an intrinsic part of the process. It recognises that merely removing certain features from an existing product to sell it cheaper in a developing society is not a viable option. The CAETS energy committee sees tremendous opportunities for the application of frugal engineering concepts in developing low cost energy-efficient buildings and building materials with local raw materials in countries such as China, India, Brazil and emerging economies to address the needs of billions of their customers. The development of people's car 'Nano' by Tata Motors in India and development of cost-effective aerospace components in China are typical examples of frugal engineering applications.

The CAETS Energy Committee also sees new opportunities for building construction agencies from developed countries to establish joint initiatives in developing countries to propagate energy-efficient systems at affordable cost. The initiatives taken by Saint Gobain, IIT Madras and other agencies worldwide are worth emulating. New opportunities will open up to avail the benefits of such bottom-up innovations by employing cross-functional teams, non-traditional supply chains and top-down support to local innovations.

THE POLICY MAKERS HAVE TO PLAY A VITAL ROLE IN DRIVING THE CHANGES AT THE GROUND LEVEL DURING THE TRANSITION TO LCE

2.3.9 Balancing Act for Objective Realisation

The CAETS Energy Committee has noted that the technology and regulatory frameworks alone are not adequate to realise the objectives of energy efficiency and emission reduction in the building sector. This is because, the value chain of this sector is quite complex with a large number of stakeholders and end users acting as non-technical barriers all too often resulting in much too little action on the field. Policy makers have to play a vital role in driving the changes at the ground level during the transition to LCE.

GOVERNMENT POLICIES FOR ENERGY-EFFICIENT BUILDINGS TO CONSIST OF REGULATIORY, INFORMATION, FISCAL AND OPERTIONAL INCENTIVES.

The major components of a government policy for achieving higher energy efficiency in new and existing buildings should necessarily consist of appropriate regulatory measures, transparency in information dissemination, well thought out fiscal and operational incentives, capacity building and institutional networking for technology access and adaption, services and funding for RD&D wherever needed for technology proving. Most of these are interactive in nature and reinforce each other to transform the market forces to react positively to the change management. They need proper balancing. While for new buildings, the policy framework has to move the market gradually towards higher energy performance levels, for energy retrofitting of the existing buildings, there is need to incentivise cost competitive and sustainable energy retrofits.

2.4 Summary

The current energy consumption in the building sector worldwide is quite substantial (>30% of all energy) and there are definite signs of its further increase (>1.5% per annum) by 2030 if corrective measures are not undertaken on the energy front. The buildings are also major emitters of GHGs with nearly 30% of them contributed by the primary energy supplied to them.

THE EXISTING BUILDINGS, HOWEVER, OFFER SEVERAL ENGINEERING CHALLENGES FOR MAKING THEM ENERGY-EFFICIENT THROUGH THE PROCESS OF RETROFITTING.

They have the largest potential for emission abatement though long gestation periods are required. There is need to deploy a mix of renewable and lower carbon energy options on a larger scale in global building sector to bring down the GHG emissions. The CAETS Energy Committee foresees the need to make a wide range of technological choices and adopt a host of novel engineering techniques to bring in a sustainable transition to a low carbon economy in the building sector. The focus has to be on advanced design, material and construction engineering. The committee, after a careful consideration of energy and GHG emission related factors, has short listed new and retrofit building envelopes, HVAC systems and advanced energy management systems (AEMS) and their upgrades as high impacting areas for achieving energy and emission reduction targets worldwide.

The process of improving the energy efficiency of new building envelopes is a high priority engineering task. There have been significant technological advances in developing energy-efficient and smart building envelopes in recent years. Integrated facading, exterior shading, well-insulated window, effective air sealing and reflective roofing technologies are vital for building envelopes. In addition, high efficiency heating/cooling, ventilation and air conditioning technologies are important. Most advanced building envelopes are cost-effective over long investment periods. The net zero and net positive energy concepts in the building sector have provided a unique opportunity for urban buildings not dependent totally on primary energy sources that are scarce. One can look at alternative renewable energy options on-site. The smart and solar envelope concepts further enhance this opportunity.

The existing buildings, however, offer several engineering challenges for making them energy-efficient through the process of retrofitting. There is a need to overcome several hurdles while planning, prioritising and prescribing the viable retrofit options. The most optimistic goal for envelope retrofits is to more than double the rate to 3% per annum. In case of HVAC systems, the building sector has always favoured a policy of retrofitting with increased efficiency and counterparts to improve return on investment and payback. The CAETS Energy committee has noted that due to high factor of safety, most of the currently used HVAC systems are over-designed. There is a need to re-design them as per scientifically evaluated heating cooling peak loads while retrofitting.

The committee has noted that the advanced energy management systems (AEMS) have been evolving fast due to rapid developments made in information and communication engineering. There is a vital need to propagate them on a much larger scale in the coming years. Computer-aided controls; energy analytics; big data engineering; and cloud-based technologies will enable the large-scale propagation of smart and energy-efficient residential and commercial buildings with minimum GHG emissions. The committee has also noted the absolute need to achieve a fine balance between technological, regulatory, non-technological factors such as government policies and incentives/disincentives to inspire the multiple stakeholders and market forces in the low cost residential building sector worldwide to hasten the transition to lower carbon energy regime.

CHAPTER 3

ENGINEERING FOR ENERGY EFFICIENCY AND EMISSION MITIGATION IN TRANSPORTATION SECTOR

CHAPTER 3

IN ORDER TO ESTABLISH A BASELINE FOR ENERGY DEMAND IN TRANSPORTATION SECTOR FOR 2030, AN ACCELERATED OR RAPID DRIVE SCENARIO IS CONCEIVED BY INTERNATIONAL BODIES TO OFFER A FRAMEWORK OF KEY ENABLERS FOR NEW PARTNERSHIPS, POLICIES AND FINANCING MECHANISM.

3.0 Defined constituencies

Derived demand for economics related human activities drives growth in the transport sector. Much of the development and operation of the transport sector in the 20th century was response driven. However, 21st century is taking a much more inclusive look at the transport infrastructure from the point of view of growing population density, new wealth creation and its impact on climate change. Although, economic factors continue to dominate growth dynamics, external costs associated with carbon emissions and environmental safety will play a larger role in determining the size and content of future transport systems. The major defined constituencies of transport sector worldwide are road, rail, sea, air and pipeline transport. There are several sub-constituencies, which need adequate attention. Appendix A (Section 1.3) highlights their basic structure, status and major issues for future development.

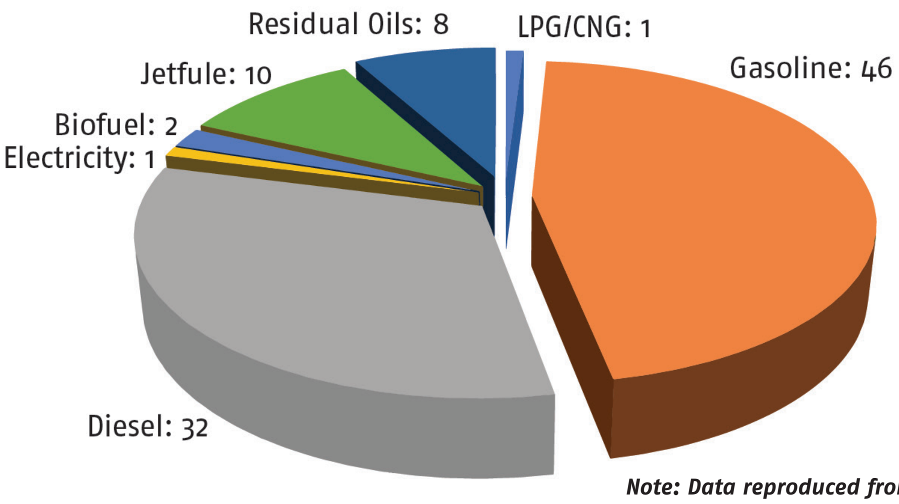
3.1 Energy and emissions from transportation sector

Worldwide, non-renewables dominate the transport fuels viz, coal, oil and gas. The World Energy Council (WEC) reported (C1) an average growth in fuel use of 1.2% for OECD countries and 4.3% for non-OECD countries during 2000-06. The per capita income and population continue to rise in non-OECD countries with significant changes occurring in their geopolitical dynamics and transportation requirements.

3.1.1 Transport Energy Sourcing and Consumption

The International Energy Agency (IEA), the World Economic Forum (WEF), the World Energy Council (WEC), the Department of Energy of USA (US-DOE) and other international agencies (C2 to C5) have independently reviewed current energy consumption pattern in transportation sector quite extensively and its outlook to 2030 and beyond. In order to establish a baseline for energy demand for 2030 in the transportation sector, the World Economic Forum, evolved (C5) an accelerated or rapid drive scenario (RDS) to adopt energy efficiency technologies that are currently available. They include reduction in energy and oil consumption, rapid uptake of electric vehicle technologies, use of alternative low carbon fuels and rapid adoption of energy efficiency technologies. The RDS provides a

Fig: 3.1.1 Breakup of Transport Energy by Source (2011)



Note: Data reproduced from Ref C1

C1: World Energy Council., Global Transport Scenarios 2050., Report with ISBN: 978-0-946121-14-4, London (2011)
C2: IEA., Global Transport Outlook to 2050: Targets and Scenarios for a Low Carbon Transport Sector., OECD/IEA Report (2012)
C3: a) IEA, Transport, Energy and CO_2 : Moving Towards sustainability; Report No.978.9264.07316.6 from IEA and OECD (2009)
b) IEA., Energy Technology Perspective 2010, IEA-OECD Report, Paris., www.iea.org (2012)
C4: US Energy Information Administration 2013, International Energy Outlook 2013., http://www.eia.gov/forecasts/ieo/pdf/0484%232013%29.pdf (2014)
C5: WEF, Repowering Transport, Project White Paper and Cross Industry Report, Geneva, April (2011)
C6: a) US DoE, Transportation Energy Futures Series: Potential for Energy Efficiency Improvement Beyond LDV sector., A Report from Argonne National Laboratory, USA, February (2013)
b) McKinsey & Co, Swiss Greenhouse Gas Abatement Cost Curve., www.McKinsey.com/--/media/mckinsey/dot.com/client_service/sust....(2007)

new framework of key enablers viz., partnerships, policies and financing mechanisms that are critical to accelerate the development and deployment of the above technologies.

OVER ALL GROWTH IN ENERGY USE IN TRANSPORTATION SECTOR WILL BE 12.5 TO 40% BY 2050.

Fig.3.1.1 gives the breakup of primary energy resources employed in the transportation sector. The scenario reiterates dominance of non-renewable fossil fuels in this sector. Table 3.1.1 shows the total energy consumption for transportation sector as reported in 2010 and its projected consumption of 289-358 billion MWh for 2030 under business as usual (BAU) and rapid deployment scenario (RD) scenarios of WEF (C5) with likely compound annual growth rate (CAGR) of 1.7% and 0.5% respectively. It means, overall growth of energy usage in transport sector can vary anywhere between 12.5% and 40% by 2030, depending on the measures taken for energy efficiency and conservation at the ground level. The global stock of transportation vehicles is likely to nearly double during 2010-30. Within transportation, the road transport sector continues to be the dominant energy user with the major share exceeding 50% claimed by the light duty vehicle (LDV) segment. The energy efficiency improvement potential is, however, reported (C6) to be most for the marine transport sector followed by the aviation and road transport sectors.

Table: 3.1.1 Global energy consumption scenarios for transport sector

Transport Sector		Energy Consumption (2010)		Projected Energy Consumption (2030)				
				BAU (CAGR: 1.7%)		RDS (CAGR: 0.5%)		EIP
		Billion MWh	% share	Billion MWh	% share	Billion MWh	% share	%
1. ROAD	LDVs	130.2	52	195.8	54.7	157.4	54.5	25
	MDVs& HDVs	54.7	21	60.7	16.9	55.7	19.3	15-30
	Sub-total	**184.9**	**73**	**256.5**	**71.6**	**213.1**	**73.8**	**--**
2. RAIL		7.6	3	10.2	2.9	6.6	2.3	15
3. AIR		25.5	10	47.2	13.2	36.1	12.5	30-40
4. MARINE		25.5	10	30.4	8.5	26.2	9.1	40
5. PIPELINE		7.6	3	--	--	--		10-20
6. OTHERS		2.6	1	13.5	3.8	6.6	2.3	NA
TOTAL		253.7	100	357.8	100	288.6	100	

Data from Ref: C5

BAU: Business As Usual Scenario; **EIP:** Energy Improvement Potential; **RDS:** Rapid Deployment Scenario **LDV:** Light Duty Vehicle; **MDV:** Medium Duty Vehicles; **HDV:** Heavy Duty Vehicles

BENEFITS OF A STRONG GHG ABATEMENT POTENTIAL IN TRANSPORT SECTOR WILL SIMULTANEOUSLY CONTRIBUTE TO IMPROVED ENERGY SECURITY.

3.1.2 Green House Gas Emissions and their Abatement Potential

CO_2 is the main GHG contributor from the transport sector. Other emissions of importance are N_2O, CH_4 and fine particulates. Table 3.1.2a provides GHG emission projections of transportation sector under BAU and RDS scenarios (C5). Global consumption of energy for transport sector as highlighted in previous section will result in increase of GHG emission from 6.83 Gtoe CO_2 emissions in 2010 to nearly 9.22 Gtoe by 2030, under the BAU scenario. The future is not sustainable under such conditions. A substantial change in GHG emission potential will result if rapid adoption of energy-efficient technologies and long-term deployment of a range of new energy options happens. The benefits of a strong GHG abatement potential in transport sector will simultaneously contribute to improved energy security.

Relative Abatement Potential of Transport Constituencies

The IEA evolved BAU and RD scenarios for assessing the abatement potential of road, air, rail and sea transport constituencies (C3a). Table 3.1.2a presents the trends for the passenger and freight transport sectors. Table 3.1.2b presents the GHG efficiency (in terms of g CO_2e/tkm) trends for four transport constituencies under BAU and RDS scenarios (C5).

Table: 3.1.2a: GHG Emission Projections of Transportation Sector

	GHG Emissions (2010)			Projected GHG Emissions (2030)			
				BAU		RDS	
	Gt CO2e	% share	t/t 0 eq	Gt CO2e	% share	Gt CO2e	% share
Road	5.05	74.0	3.01	6.56	70.5	5.01	72.1
Rail	0.08	1.2	1.21	0.09	1.0	0.08	1.2
Air	0.75	10.9	3.41	1.24	13.3	0.70	11.8
Marine	0.78	11.4	3.50	0.91	9.8	0.85	12.5
Pipeline	0.17	2.5	2.5	0.50	5.4	0.16	2.4
	6.83	**100.0**		**9.30**	**100.0**	**6.8**	**100.**

BAU: Business As Usual; RDS: Rapid Deployment Strategy ***Data from Ref: C5***

THE GROWTH IN GHG EMISSIONS FROM TRANSPORTATION SECTOR IS STILL IN TUNE WITH GDP GROWTH OF COUNTRIES WITH ITS CURRENT ANNUAL GROWTH WORLDWIDE OF AROUND 2%.

Table 3.1.2b: GHG Efficiency Trends (2005-50) for Transport Constituencies

Transport	GHG Intensity*			Freight Transport** (2005)
	Passenger Transport (2005)	BAU-2050	RDS-2050	
Sea	-	-	-	4-20
Rail	20-55	18-48	1-12	10-30
Road				
- Trucks	-	-	-	250-800
- Buses	30-38	28-75	15-30	-
- LDVs	80-285	75-180	10-30	-
- 2 Wheelers	30-125	35-75	10-30	-
Air	225-250	170-200	100-110	700

gCO2 e/passenger – km **g CO2 e/tonne – km; LDV: Light Duty Vehicles;* ***Data from Ref: C5*

Data presented in Tables 3.1.2a and b clearly shows that:

- Rail (passenger and freight) and marine (freight) transport have the minimum GHG intensity followed by light duty road transport. Air transport and heavy duty road transport have the highest intensity.
- Substantial improvement in GHG efficiency of all modes of transport can occur by 2050, with a variation in their degrees of reduction.
- Light duty passenger vehicles have a wide band of GHG efficiencies due to geographical variation of energy usage and quality of fuel employed.

RAIL AND MARINE TRANSPORT HAVE THE MINIMUM GHG EMISSION INTENSITY FOLLOWED BY LIGHT DUTY ROAD TRANSPORT

The IPCC prefers (C7) that the CO_2 concentration in the global atmosphere is stabilised at 450 ppm level since this would provide a good chance of limiting the global temperature rise to 2^0C. At this level, the GHG emission impact will limit the environmental damage. In order to meet such a target, a 50% reduction of GHG emissions from the present levels will be necessary by 2050.

The CAETS Energy Committee has noted that the growth in GHG emissions from transportation sector is still in tune with GDP growth of countries with its current annual growth worldwide of around 2%. Much of this growth is due to steep increase in number of transport vehicles and international travel. The committee is of the opinion that the GHG emission trends in 2020 in transportation sector may still be far from the trajectory as desired by the IPCC. The need for more aggressively planned transition programmes to low carbon economy, therefore, becomes a priority and indeed a necessity.

C7: International Transport Forum (ITF), Reducing Transport GHG Emissions: Opportunity and Costs, Report on Preliminary Findings by OECD/ITF (2010)

IT IS A CONCERN THAT GHG EMISSIONS IN SEVERAL COUNTRIES GROW IN TUNE WITH THEIR GDP AND THEIR GLOBAL INCREASE CONTINUES TO GROW AT 2%.

CHANGES DUE TO SHIFTS IN TRAVEL MODES GREATLY DEPENDS ON CONSUMER BEHAVIOR PATTERNS

Emission Reduction through Demand Management

Quantification of the possible changes due to shifts in travel modes is difficult, largely because it depends on consumer behavioural patterns. The relationship between transportation and the spread of urban settlements is interactive. The building of railroads and highways has influenced urban development, and conversely the growth of urban areas has influenced the development of road, air, and rail networks that facilitate travel within and across urban areas. The transport modal choices based on smart city concept differ from place to place due to variations in socioeconomic conditions and urban development policies (C8). Urban design and personal transport choices influence people's behaviour and decision-making process. The very compact nature of a city and its governing policies can contribute to the reduction of private motor vehicles largely. On the other hand, a sprawling city with large distances between its localities coupled with the government's liberal fuel policies can contribute to significant movement by private motor vehicles and sizeable GHG emissions from passenger transport, as a result.

Private motor vehicles have a larger footprint per passenger-km than motorised public transport and the latter has a larger footprint than rail transport. If different modes are not properly integrated, the apparent benefits of public over private transport would reduce and the opportunity for reducing carbon emissions is totally or partially lost. The role of urban transport design is thus a major factor in optimising the transportation needs. The IEA evolved the Blue Map/shift scenario (C3a) which takes into account efficiency improvement, new vehicles and fuel technologies and modal shifts. It anticipated 40% reduction in CO_2 below 2005 levels by 2050.

Multimodal Transport and Emission Reduction

Multimodality involves integration of various modes of transport in a given region and has the potential to leverage advantages of its constituent modes to enhance its overall efficiency. In general, use of seamless multimodality and environmentally sustainable modes within its chain are major factors for GHG emission reduction. So far, the engineering developments in multimodal transport are mainly seen in planning, construction, management and sustainable growth. There are some efforts towards the use of synergetic approaches for evolution of multimodal transport systems with reference to emission reduction (C9). It is generally believed that the creation of a multimodal transport system grouping together walking, cycling and use of public transport can save the amount of CO_2 generated by three times. The development of a sustainable multimodal transport poses a challenge to engineers and technologists. There is a need to employ novel engineering concepts for land use integration, network design, achieving a rational mix of various transport modes and routes and access points with evolving intelligent control systems to facilitate sustainable multimodality

Predictive Tools for GHG Emissions from Transport Systems

The CAETS Energy Committee highlights the need to use modern engineering tools to pre-assess GHG emission inventories for various transport constituencies to integrate environmental considerations for transportation decision making and for target setting at national or regional level. Several simulation models have been reported in recent years for a variety of transport constituencies to assess the emission reduction trajectories for a given travel activity (C10). They generally focus on estimating person miles travelled as a prime metric with other key factors being the type of fuel and its consumption, transportation vehicle operating characteristics and other downstream-related factors. The relationships between these factors and GHG emissions are not simple. CO_2 emission from energy sources depends on fuel mix combusted and emission factors, which are specific to the concerned

C3: a) IEA, Transport, Energy and CO_2: Moving Towards sustainability; Report No.978.9264.07316.6 from IEA and OECD (2009)

C8: Smart Cities Cornerstone Series, Urban Mobility in Smart City Age, Report by Schneider Electric, Arup and The Climate Group, Digitial.Arup.Com/WP-content / uploads / 2014 /06Urban-mobility.pdf

C9: D.M.Ecorys, ITS in Traffic Management, Multimodal Transport and Reduction of C02 Emissions: Results and Challenges., www.amitran.eu/.../ ITS.... 2013/Amitran-Results-Challenges, Nearctis-ITS, 6 June (2013)

C10: ICF Consultants, Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects, Report for American Association of State Highway and Transportation Officials (AASHTD), May (2008)

THE GERMAN GOVERNMENT FORMULATED ENERGY AND EMISSION REDUCTION CONCEPTS IN 2010 TO SPECIFY GHG EMISSION REDUCTION TARGETS FOR 2050.

SOCIAL COSTS OF EMISSION REDUCTION ARE LOW (EURO 40 PER TONNE) BUT IMPLIED CAPTIAL COSTS FOR INVESTORS IS HIGH (EURO 160 PER TONNE)

fuels and countries. Techniques such as pre and post-combustion carbon capture are useful for evaluation of emission reductions. Factors such as anticipated travel demand, fuel conservation and their changes from time to time are important. The European Union employed model-based approach in 2012 for quantification of emission scenarios pertaining to aviation fuels for achieving beyond 20% GHG reduction by 2020 (C11). The Japanese have reported a simulation model (IEEJ 2050) in 2012 to project world transport energy and emission scenarios for 2050 (C12a). The German government formulated energy and emission reduction concepts in 2010 to specify GHG emission reduction targets for 2050 (C12b).

The CAETS Energy Committee has noted the positive and negative aspects of various models reported for pre-assessing GHG emissions from various transport systems. Most of them are economic outcome driven. Their major engineering drawbacks arise from lack of representative concentration pathways, non-linear responses of the pollutants and unrealistic assumptions made while constructing the emission scenarios. There is, therefore, a need to exercise caution while employing model-based approach for pre-assessing the emission reduction prospects. Engineering efforts have to continue to improve these models.

Techno-economic Trends of GHG Emission Abatement

Quantifying techno-economic benefits of GHG abatement in transportation sector is extremely difficult due to uncertainties in assessing the consequences of climate change, selection of options and assessing rate of returns on the long-term options, disproportionate impact of upfront costs on energy efficiency and unknown future of new fuel options. The International Transport Forum (ITF) examined techno-economic implications of GHG emission reduction in transportation sector (C7). The cost studies have shown that the net average social costs of emission reduction are low (euro 40 per tonne) but the implied capital costs to be borne by the investors and consumers are high (euro 160 per tonne). This trend provides a potential rationale for government policy and fiscal interventions. Schade and Krail (C13) have evolved a GHG mitigation strategy for the European transportation sector based on scoping of their emission reduction potentials. Measures such as lightweight construction, solar vehicle roofs and exhaust heat recovery are technology driven. Their impact on emission reduction would depend on costs, barriers and interaction between various measures. Each measure is evaluated for costs, by considering R&D, scale-up, intellectual property protection, production costs and sales expenditure. These studies have shown that 60% GHG reduction target for 2050 is achievable at affordable cost.

McKinsey & Co. have evolved GHG Abatement cost curve concept (C14) for assessing the GHG abatement potential of various sectors of the global economy. It is deduced after an in-depth evaluation of more than 200 GHG abatement opportunities across 10 sectors of global economy and 21 world regions. It can serve as a starting point for engineers, corporate leaders and policy makers to identify measures and investments required to achieve the desired emission reductions. These studies have identified the GHG emission abatement potential of the transport sector as 2.6 Gt CO_2e per year by 2030 compared to 3 Gt CO_2e per year for the building sector. The investment requirement of the former is about 94.2 billion euros per Gt CO_2e by 2030. It is based on the premise that technical measures will cost less than euro 60 per tonne CO_2 eq abated. This level of abatement could put emission on track to meet a trajectory of 450-ppm atmospheric CO_2 concentration. The CAETS Energy Committee has noted that ITF projections have less optimistic outlook than that of McKinsey's. The committee observed that McKinsey studies account for emission reduction from forestry, agriculture and land use change in addition to transportation.

C7: International Transport Forum (ITF), Reducing Transport GHG Emissions: Opportunity and Costs, Report on Preliminary Findings by OECD/ITF (2010)
C11: P.Capres, NoTaSioS eta, Analysis of Options to Move Beyond 20% GHG Emission Reduction in the EU by 2020: Member State Results, A EU Report to DG Climate Action, January (2012)
C12: a) S.Suehiro, Outlook for Energy and Transport Demand in the Road Sector, Paper from IEEJ presented in 2nd Workshop for Automobile and Energy, Japan, 29 March (2012)
b): MFS, The Mobility and Fuels Strategy of the German Government, www.bmvi.de/sharedDocs/EN/Analogen/UI-MKS/mfs-strategy-final(2011)
C13: W.Schade and M. Krail, GHG Mitigation Strategy in the European Transport Sector, Transport Research Arena, Paris (2014)
C14: McKinsey & Co, Impact of the Financial Crisis on Carbon Economics, Version 2.1 of the Global GHG Abatement Cost Curve (2010)

RENEWABLE SOURCES SUCH AS WIND AND SOLAR POWER HAVE STARTED RECEIVING MORE POSITIVE RESPONSE FROM TRANSPORT SECTOR NOW THAN IN THE PAST.

Table 3.1.3: Carbon Intensities of fuels and Travel Modes

Carbon Intensity of Fuels, g CO_2 / KWh		Carbon Intensity of Travel, g CO_2 / p Km	
COAL	1001	Road Transport	
OIL	840	- LDV	138-301
NATURAL GAS	469	- EV	123
BIOFUELS (1st Generation)		- SEV	50
- Palm	204	- Hybrid LDV	116
- Soya	188	- HDV	182
- Sunflower	130	Rail Transport	
BIO ETHANOL		- General	116
- Corn	370	- Metro	50
- Sugarcane	222	- High Speed	20
- Cellulose	74	Air Transport	120-139
SOLAR		Cycling	17
- PV	46		
- CSP	22		
WIND	8		
NUCLEAR	16		

pkm: passenger km

3.1.3 Alternative Energy Resources for Transportation

Carbon Intensity as a Guiding Factor for Alternative Fuel Selection

The carbon intensity is generally expressed in terms of CO_2 released per unit of power generated (C15 to C17). In a particular travel mode, the intensity is in terms of CO_2 emission resulting directly from fuel combustion in a transport vehicle or indirectly from the production process of electricity used by it or both. Table 3.1.3 provides typical carbon intensities of fuels and travel modes. For example, coal releases twice as much CO_2 as natural gas. This is the main reason for several countries switching over to natural or shale gas from coal or petroleum oils as energy feedstock. The carbon intensity thus provides a realistic rationale for switching over to lower carbon fuels.

Alternative Energy Options

The IEA projects that biomass could provide about 9.3% of transportation fuels by 2030 (C3a) and it can increase to 26% by 2050 (C3b). The transport sector currently relies heavily on liquid fossil fuels. The potential alternative energy options to non-renewable oil resources for the transportation sector are natural gas, biofuels, hydrogen, electricity, solar, wind and nuclear energy. In recent years, the road, rail and sea transport constituencies have shown preference for natural gas (CNG and LNG), shale gas and biofuels. The need to reduce carbon intensity drives these decisions. The complementary renewable sources such as wind and solar power have started receiving more positive response now than in the past.

OTHER POTENTIAL RENEWABLE ENERGY SOURCES ARE BIOFULES HYDEROGEN AND NUCLEAR

Global production of liquid biofuels for transportation sector could reach 100 billion litres in 2015. This constitutes around 3% of total road transport fuel with considerably higher share achieved in countries such as Brazil (e.g. about 23%). First generation liquid biofuels come from several biological feedstocks including corn, sugar, bagasse and vegetable oil. Their further growth becomes restrictive due to their conflict with biodiversity, and water and food supply chains in several countries. The second-generation biofuels could overcome these

C3: a) IEA, Transport, Energy and CO_2: Moving Towards sustainability; Report No.978.9264.07316.6 from IEA and OECD (2009)
b) IEA., Energy Technology Perspective 2010, IEA-OECD Report, Paris, www.iea.org (2012)
C15: F.Posada, C.Maline and A Baral, Biodiesel Carbon Intensity, Sustainability and Effects on Vehicles and emissions, International Council on Clean Transportation (ICCT), Briefing, January 2012.
C16: Clean Technica, Electricity Source With Lowest Carbon Intensity, 15 April (2014)
C17: DEFRA, 5 Elements of Sustainable Transport, Shrinkthat Footprint.com

A AUSTRALIAN STUDY HAD SHOWN THAT THE FUTURE GROWTH OF BATTERY VEHICLES AND THEIR CHARGING SYSTEMS DEPEND ON ELECTRIC GRID PERFORMANCE TO OVERCOME POWER INTERMITTENCY.

GLOBAL TARGET IS TO REDUCE FUEL CONSUMPTION OF NEW CARS BY 30% BEFORE 2020 AND BY 50% PRIOR TO 2050

bottlenecks in a big way, since they will come from lignocellulosic biomass or woody crops, agricultural residues and other wastes. These technologies are under development.

Direct use of clean electricity is one of the most attractive alternative options for the transportation sector. Battery powered road transport vehicles are likely to register higher growth in the future due to an increase in their specific energy and life cycle costs while their manufacturing costs have fallen quite sharply. A study by the Australian Technological Science and Engineering (ATSE) had shown that the future development of battery vehicles and their charging systems depend on improvements in electric grid performance with reference to power intermittency (C18). Tesla Electric Motors in USA have revolutionised the automobile engineering with a single moving part viz., the rotor, which provides instantaneous acceleration to a car. The working principle of the hyper loop in a Tesla car is same as that of a MAGLEV train, which levitates and moves forward using powerful electromagnets. This type of motion significantly reduces friction losses. The absence of air in the hyper loop further increases its efficiency due to minimised air drag. It makes the entire system move much faster. It gives 100% torque in an instant. With two motors, one can independently control torque in the front and rear wheels to provide unparalleled traction control in four-wheel drive vehicles.

At present, air transport is most dependent on crude oil based secondary fuels (99+%) and has few alternatives. However, since 2008, some of the major airlines in the world have formed the Sustainable Aviation Fuel Users Group (SAFUG) for conducting test flights with biofuels (C46). Their feedstocks include soya, camelina, jatropha, oil palm and algae. This Transportation Group has launched a series of global initiatives to make aviation biofuels ready for commercial application (C19). Prospects for solar power in aviation sector are slowly emerging. It still has to mount enormous engineering challenges before its field potential is established (C20). At present, its application is limited to auxiliary power systems.

3.1.4 Regulatory Framework for Energy Efficiency and Emission Control

Transportation is one sector in which regulations are highly effective to reduce GHG emissions (C21 and C22). This section briefly reviews the evolving regulatory framework in the four major transport constituencies.

Road Transport

The European Union has set its emission standards viz., Euro-4 (2008), Euro-5 (2010) and Euro-6 (2016). Large countries such as China and India have established their own emission performance standards. ISO 39001 provides the international standards for road traffic and safety. EU and Japan have promoted energy efficiency of IC engine vehicles through indirect taxes on fuel sales. The US regulations for energy efficiency in automobiles is based on the Corporate Average Fuel Economy (CAFE) standards which initially set 27.5 mpg as target and is now being revised to 35 mpg to be achieved by 2020. The USA has also implemented regulations on older vehicle scrapping, incentives to low fuel consuming vehicles, carbon commitment on new vehicles, incentives to create telecommuting infrastructure and encouragement for car ride sharing. The Federation of International Automobiles (FIA), IEA, ITF and the UNEP established the Global Fuel Economy Initiative recently to evolve appropriate policies to make road transport vehicles more energy-efficient and to overcome current obstacles for its smooth implementation. The target is to reduce the average fuel consumption of new cars by 30% by 2020 and by 50% by 2030.

C18: Energy White Paper, ATSE Report to the Department of Industry, Government of Australia (2013)

C19: F.R.Calle, S.T.Singh et al., The Potential and Role of Biofuels in Commercial Air Trnasport – Biojet fuel, A Report from Imperial College, London and Helmholtz Centre for Environmental research, August (2012)

C20: Mybroadband., Solar Powered Planes could Replace Satellites., The Conversation, 14 March (2015)

C21: R.Smokers, H.V.Essen, B Kampman, ED Boer and R Sharpe, EU Transport GHG: Routes to 2050, A Report on Regulations for vehicles and Energy Carriers by AEA/CE Delft/TNO/ISIS., 12 February (2010)

C22: UNFCCC, Methodological Issues under the convention: Emissions from Fuel used for Internatioanal Aviation and Maritime Transport Agenda 10(d) of 36th Session of Subsidiary Body for Scientific and Technical Advice, Bonn, 14-25 May (2012)

C46: Wikepedia, Aviation Biofuel, en.wikipedia.org/wiki/Aviation-Biofuel (2014)

VISION DOCUMENT OF INTERNATIONAL TRANSPORT FORUM FOR RAILWAYS PREDICTS 17%DROP IN ENERGY INTENSITY BY2030

POLICY FRAMEWORKS FOR SUSTAINABLE DEVELOPMENT OF RAIL AND AVIATION SECTORS WAS CONCEIVED IN 2010

Japan is the first country in the world to introduce fuel economy standards for heavy-duty road transport vehicles and these are to improve by 12% from 2002 to 2015. The Japanese Academy of Engineering (EAJ) compared the performance of Japanese cars in terms of relationship between fuel expenses and car weight, maximum power and maximum torque (Appendix A1.5). The IEA in 2010 made recommendations on energy efficiency in road transport through, fuel efficient tyres and eco-driving (C23). The latter is for heavy-duty vehicle drivers and their supporting staff. There are online as well as classroom training packages. They cover GPS tracking, route planning and monitoring, integrated navigation, wireless security systems, alarm generation and actual route execution. In 2013, International Council on Clean Transportation (ICCT), an independent non-profit organisation made a comparative study of international fuel economy of light duty vehicles (C24).

Rail Transport

International Rail Transport Committee (CIT), an organisation of 200 railway undertakings helps railways across the world implement international rail transport laws. The inter-governmental Organisation for International Carriage by Rail (OTIF) in Switzerland frames the regulations for transport of dangerous goods. The transport division of United Nations Economic Commission for Europe (UNECE) aims to improve safety, energy efficiency and security in rail transport. It also focuses on reducing adverse effects of transport activities on the environment. There are no specific rail regulations focussing on energy efficiency or GHG emission control. The vision document prepared by the International Transport Forum (C6) for railways in 2010 predicted that locomotive fleet energy intensity will decrease by 13-17% by 2030 and improved engine design in terms of injection, brake energy recovery, turbocharging and system cooling can reduce fuel consumption by 20%. Considering the expected increase in rail activity worldwide, the fleet energy intensity will improve 35% and the energy consumption in 2050 may be just around 2010 levels. The best rail alternative fuels are likely to be electricity, biodiesel blends and liquefied natural gas (LNG).

Air Transport

The United Nations Framework Convention on Climate Change (UNFCCC) through International Civil Aviation Organisation (ICAO) in 2010 has suggested a robust policy framework for sustainable development of international aviation (C22). A global CO_2 certification standard is likely to be set. There is a plan to set a goal of 2% improvement in fuel efficiency every year and make aviation the first sector in the world to have global regulations on energy efficiency. The EU in 2012 has established an Emission Trading System (ETS) for aviation sector within its economic area. International Air Transport Association (IATA) policy formulations has three environmental goals viz., improving fuel efficiency by 1.5% per annum during 2009-20, carbon neutral growth from 2020 onwards and 50% reduction in net aviation carbon emissions by 2050. It provides national governments with a set of principles and standards to implement.

Marine Transport

United Nations Conference on Trade and Development (UNCTAD) reviewed legal and regulatory issues relating to GHG emissions in marine transport systems (C25). The International Maritime Organisation (IMO) has adopted technical and operational measures in 2013 under the energy efficiency framework for marine vessels. Successful implementation of these measures is likely to reduce shipping CO_2 emissions to 1.3 giga tonnes per annum. The IMO has recently committed itself to reduce CO_2 emissions by 25% to 75% in case of newly built as well as operating ships by giving increased focus on energy efficiency (C26). Concept of ships displaying their energy performance through appropriate design and operation indices is receiving attention. There

C6: a) US DoE, Transportation Energy Futures Series: Potential for Energy Efficiency Improvement Beyond LDV sector, A Report from Argonne National Laboratory, USA, February (2013)
b) McKinsey & Co, Swiss Greenhouse Gas Abatement Cost Curve, www.McKinsey.com/~/media/mckinsey/dot.com/client_service/sust....(2007)
C23: K.Kojima and L Ryan, Transport Energy Efficiency: Implementation of IEA Recommendations Since 2009 and Next Steps, Information Paper from IEA, September (2010)
C24: P.Benoit, Energy Efficiency: Supporting Our Climate Goals, Report to ADP Technical Experts Meeting on Energy Efficiency, Bonn, 12 March (2014)
C25: UNCTAD, Review of Maritime Transport, (2013)
C26: ABB, Powering the World's High Speed Rail Networks, Background Information, www.abb.com/railway(2014)

THE BEST STRATEGY TO INCREASE ENERGY EFFICIENCY OF ROAD TRANSPORT VEHICLES IS THROUGH IMPROVEMENTS IN ENGINE EFFICIENCY AND THEIR ON-ROAD PERFORMANCE.

THE INTERNATIONAL MARITIME ORGANISATION (IMO) HAS ADOPTED TECHNICAL AND OPERATIONAL MEASURES IN 2013 UNDER THE ENERGY EFFICIENCY FRAMEWORK.

is a proposal for variable speed drives for on-board cooling, chilled water pumps and room ventilation fans. It has been reported that the shipping industry will introduce energy monitoring and management (EMMA) tools for achieving the best possible energy efficiency in their operations.

Considering the above developments, the CAETS Energy Committee opines that current transportation sector regulations are predominantly emission control driven and have several limitations for achieving higher energy efficiency. Targeting energy efficiency and GHG emission reduction together is desirable though they have their own dynamics and time scales for developing new technological and engineering options. The following factors are important for evolving regulations for achieving energy efficiency expeditiously in the transport sector.

- New regulatory framework in transportation sector should be technology neutral and allow adequate flexibility to the manufacturers to comply with the targets and to be globally competitive.
- New initiatives such as vehicle energy efficiency labeling, linking vehicle tax to congestion pricing, to reduce vehicle trips, modal shifts to encourage public transport, carbon commitment for new vehicles, pay and drive insurance schemes and traffic privileges to low fuel consuming vehicles need to be implemented on a wider scale.
- Use of attribute-based standards such as CAFE of US to quantify fuel economy targets for each class of vehicle as per its desirable emission footprint is worth pursuing at global level with appropriate modifications.

The committee advocates the need to establish a fine balance between the regulations on energy efficiency and emission control, incentives/disincentives and punitive actions at national level.

3.2 Engineering of energy-efficient transportation systems

Energy efficiency and emission reduction in transportation needs special attention from the engineering standpoint. A higher level of multi-disciplinary engineering skills is required. The CAETS Energy Committee has prioritised the engineering of energy-efficient light-duty road transport vehicles, locomotive, aero and marine engines and their energy management systems for technology and engineering review in this section.

3.2.1 Road Transport

The best strategy to increase energy efficiency of road transport vehicles is through improvements in engine efficiency and their on-road performance. These constitute the main subjects of research/academic institutions and automobile manufacturers with the driving force created by national policies, regulatory mandates and other socioeconomic compulsions. Introducing new fuel efficient propulsion technologies and lower carbon fuels is very challenging from management point of view because of poor coordination between fuel and vehicle industries, large upfront investments needed for infrastructure and growing consumer expectations on energy and emissions reductions. The focus of energy efficiency and emission reduction measures in transportation sector is mainly on light duty vehicles (LDVs) since their energy consumption alone account for more than 50% of the transport sector. National Research Council of USA has projected a reduction of 35% in fuel consumption by LDVs by 2034, just through evolutionary improvements in their energy efficiencies (Table 3.2.1a). BEVs and HFCVs represent a leap forward in energy efficiency achievement.

Energy-efficient vehicles with reduced GHG emissions would cost 10% to 30% more in case of current vehicles with improved efficiency. Electric and fuel cell vehicles may cost 25% to 30% more. The US Department of Energy (US-DOE) has made an assessment (C27) of the improvement potential of non-LDV transport systems including medium and heavy duty trucks, buses, aircraft, marine vessels, trains and pipeline transport systems (Table 3.2.1b). The study shows that air and sea transport sectors have the highest possibility for energy

C27: Transportation Energy Future Series: Commercial Trucks, Aviation, Marine Modes, Railroads and pipelines and Off Road Equipments, A Study by Argonne National Laboratory, IL, USA-DOE (2013) efficiency improvement, followed by medium and heavy-duty vehicle sector during 2030-50. A number of technological and engineering improvements such as low rolling resistance tyres, turbo compounding and bottoming cycles for waste heat recovery, improved aerodynamics, hybrid fuel systems, light weighting are the current directions of energy engineering research.

Table 3.2.1a: Plausible Fuel Reductions and Cost Enhancement of Road Transport Vehicle Engines

Propulsion	**Fuel Consumption in Gasoline Equivalent relative to IC engines**	**Anticipated Price Increase of a Vehicle in US$ (at 2007 price level)**	
		LDVs	HDV
Current Gasoline ICE	1	-	-
Current Diesel Engine	0.8	1500	1900
Current Hybrid Engine	0.75	4400	5700
Advanced Gasoline ICE	0.65	1800	2200
Advanced Diesel Engine	0.55	3000	4000
Advanced Hybrid (HEV)	0.4	2500	3000
Plug in Hybrid (PHEV)	0.2	3900	5300
Battery Electric Vehicle (BEV)	Nil	8000	12000
H_2 Fuel Cell Vehicle (HFCV)	Nil	4500	6200

Data reproduced from C27

LIGHT DUTY VEHICLES (LDVS) CONSTITUTE A MAJOR PART OF TRANSPORT VEHICLES.

Table 3.2.1b: Energy Efficiency Improvement Possibilities of non-LDV Transport Systems by 2030

Transportation	**Energy Efficiency Improvement**
Medium/Heavy Duty Vehicles	15-30
Air	30-40
Marine	40
Rail	15-17
Pipeline	10

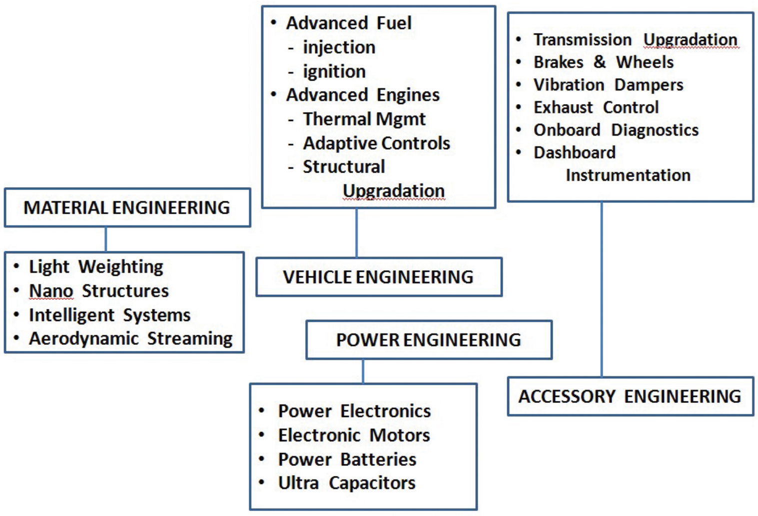
Data reproduced from C27

3.2.1.1 Advanced Road Transport Vehicle Engines

LDVs constitute a major part of transport vehicles. Their fuel economy has improved from 6 to 10 km per litre during 1978-2012 thanks to technology innovations in advanced LDV engines. The IC engines will remain the mainstay for several years to come. Fig.3.2.1.1 indicates various techno-engineering options available for enhancing LDV engine efficiency.

Table 3.2.1b: Energy Efficiency Improvement Possibilities of non-LDV Transport Systems by 2030

LDV FULE ECONOMY HAS IMPROVED FROM 6 TO 10KMS PER LITER DURING 1978-2012



VARIABLE FUEL INJECTION, HOMOGENEOUS CHARGE COMPRESSION IGNITION AND DIRECT INJECTION TURBO ARE PROMINENT ENERGY REDUCTION OPTIONS IN IC ENGINES.

A direct fuel injected dual charged IC engine with high specific capacity enhances the energy efficiency by at least 20%. The diesel and gas fuelled engines offer attractive fuel consumption levels as compared to petrol fuelled IC engines. Incremental improvements in terms of variable compression fuel injection, homogeneous charge compression ignition (HCCI) and use of engine configuration variants such as spark ignited direct injection turbo (SIDIT) and direct injection turbo (DIT) with exhaust gas recirculation (EGR) can increase fuel utilisation efficiency by 10-15%. Atkinson cycle and advanced diesel versions have good prospects for achieving higher energy efficiency. There is need for advanced cooling technologies and waste heat recovery systems for better thermal management of advanced engines. In addition, there is a need for adaptive controls and after-treatment facilities for particulate matter and non-precious metals for their uninterrupted functioning.

Table.3.2.1.1 shows the impact of engine improvements on fuel consumption. The use of lightweight materials in road transport vehicles will more than double in the next decade to reach US$ 450 billion market for high strength plastics, sandwich materials, magnesium, carbon fibre and other lightweight materials. There is a need for vehicle manufacturers to adopt strategies for specific material weight reduction, considering factors such as formability, strength, temperature resistance and cost. The automotive industry can benefit from the experiences of aviation sector in these areas.

Table: 3.2.1.1: Fuel Reduction Prospects for Various Engines

Engine Type	Fuel consumption relative to gasoline engines, per unit quantity
Gasoline	1
Diesel	0.8
Hybrid	0.75
Advanced Gasoline	0.65
Advanced Diesel	0.55
Advanced Hybrid	0.4
Plug-in hybrid (PHEV)	0.2

Data reproduced from C31

VEHICLE MANUFACTURERS HAVE TO ADOPT STRATEGIES FOR SPECIFIC WEIGHT REDUCTION.

The other important fuel economy engineering interventions are multivalve engines with variable timing and lift, direct fuel injection with lean or stoichiometric fuel mixtures, engine under-sizing and turbo charging and deactivation of 6 and 8 cylinder engines. In diesel engines, IDI engines can be replaced by high speed direct injection (HSDI) engines employing 4 valves / cylinder and use of common rail diesel injection (CRDI) system turbocharged with intercooling. Options such as idle stop-start systems and integrated starter-generators are also available. Modern power transmission systems employ six and seven gears or continuously variable transmission (CVT) on front-wheel drive models.

The CAETS Energy Committee has noted that the present medium duty (MDVs) and heavy duty vehicles (HDVs) are predominantly diesel engine based with around 45% thermal efficiency. The first transition to LCE in this segment is achievable through switchover to natural gas (CNG or LNG) or biofuels or hybridisation. HCCI for natural gas fuelled MDVs and HDVs has a high priority for limiting NOx and other emissions. Other options such as variable geometry turbo charging and multiport fuel injection under pressure are gaining importance. Hybrid MDV/HDV power trains based on electric, hydraulic and flywheel options will receive increased attention in the coming years.

Material Science and Engineering

The light weighting of engines and vehicle bodies plays a major part in enhancing energy efficiency and emission reduction in transport vehicles. A common rule of thumb is that a 10% weight reduction can reduce fuel consumption by 5% to 7% when accompanied by appropriate

ACHIEVING A TRADE-OFF BETWEEN ENGINE EFFICIENCY VEHICLE SIZE/ WEIGHT AND FUEL CONSUMPTION IS AN ENGINEERING CHALLENGE

ELECTRIFICATION OF ROAD TRANSPORT VEHICLES IS A POTENTIAL GAME CHANGER WITH A HIGH SOCIOECONOMIC IMPACT

engine downsizing. The importance of material engineering is clear from past experiences, which showed improvement in engine performance not contributing to lower fuel consumption due to an increase in vehicle size and weight. Achieving a trade-off between engine efficiency, vehicle size/weight and fuel consumption is an engineering challenge. Plastics account for 15% of materials employed in road transport vehicles. These materials include high performance polycarbonates, versatile PU foams and a wide range of cutting-edge coatings and films. The current focus is on development of lightweight materials including novel composites (C28, C29). Recent engineering advances on layered materials, making use of special influence of material interfaces and nanoscale inorganics have greatly contributed to their development. Performance of vehicle components has improved by employing more intelligent materials and polymers. The light materials currently used are aluminium, magnesium, high strength steels and carbon composites. Most of them are expensive. Aerodynamic studies on vehicles go hand in hand with lightweight material development. German engineers have developed a light truck superstructure weighing less than 5,400 kgs. Significant engineering research is being undertaken in USA, Germany and Japan for automated processing of new materials, development of lightweight materials for suspension, brake fittings and wheels and surface engineering for improved wear resistance and minimising contact damage.

Electrification of Road Transport Vehicles

The CAETS Energy Committee considers electrification of road transport vehicles as a potent game changer during transition to LCE, with a net positive environmental and socio-economic impact. Electrical Vehicles (EVs) employ traction motor powered through external electricity or on-board batteries or fossil fuel driven generators. Much greater emission reductions and energy efficiency improvements are possible by employing electric drive propulsion technologies. These include hybrid gasoline-electric vehicles (HEVs), plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs). The latter carry much larger rechargeable battery pack to power electric driving to 100 km or more. These approaches can reduce fossil fuel consumption by 75%. Large-scale adoption of battery technologies requires battery life enhancement beyond 10 years. All electrical vehicles can achieve a tank to wheel efficiency at least twice that of conventional gasoline vehicles.

Significant technology and engineering developments are taking place in EVs in the road transport sector (C30). The electric motors employed in them are generally synchronous with a permanent magnet in the rotor. The stator's rotating magnetic field imposes an electromagnetic torque on the rotor causing it to spin in synchrony with the stator field. There have been engineering advances to improve the magnet materials (e.g., neodymium) and motor compactness. Asynchronous induction AC motors that do not require strong permanent magnets are under test, since they can tolerate a wider range of temperatures and are robust. TESLA Cars use them. These motors do not require conventional multispeed gearbox since they function efficiently at high loads without overheating.

Gasoline-electricity hybrid vehicles employ advanced technologies to maximise fossil fuel utilisation efficiently, to reduce its consumption and cut down GHG emissions. The electric motor serves dual roles of supplemental power source to the IC engine as well as a generator to recharge the battery pack (C31). HEVs employ batteries charged by an internal combustion motor equipped with regenerative braking system. The drive may be from both or either of them. In recent years, integrated motor assist (IMA) and electronically controlled variable transmission (eCVT) technologies are coming into prominence. In case of PHEVs, parallel and series concepts with drives either battery or IC engines or both options are gaining acceptance. The series platform enables them to operate on battery capacity until depleted to a definite level. In case of BEVs, efforts are

C28: cKinsey & Company, Lightweight, Heavy Impact, www.mckinsey.com/^/media/mckinsey/dotcom/client-service/auto.... (2012)
C29: SBAC Aviation and Environment Briefing Papers: 8 Advanced Aircraft Materials, www.sustainable avaiation.co.uk/wp-content/uploads/advanced – aircraft....(2008)
C30: World Nuclear Association, Non Power Nuclear Applications: Transport, www.world.nuclear.org/info/non power...../Transport / Electricity-and-cars/, January (2015)
C31: D.Sperling and N.Lutsey, Energy Efficiency in Passenger Transportation, The Bridge 39(2) Summer (2009) of National Academy of Engineering, USA.

RECOVERY OF BRAKING ENERGY, LATENT HEAT ACCUMULATION FOR STARTUP AND ADVANCED ENGINES ARE PRIORITIES FOR RAIL TRANSPORT

on to create 35+ kWh on board employing lithium magnesium oxide batteries with regenerative braking system.

The CAETS Energy Committee forecasts major technological and engineering breakthroughs in EV body: light weighting, chassis, charging facilities, energy storage, thermal management and automation/control. The committee anticipates new technology initiatives for carbon composite based lightweight structuring for these to weigh less than 1,600 kg, moulded plastics compounded with micro cellulose for EV chassis and copper hybrid traction motors in the coming decade. Similarly, engineering advances can take place in lithium–sulphur and lithium–oxygen batteries with 500-1,000 watts hours/kg energy density and ultra-capacitors. There are also possibilities for development of advanced automation and predictive control systems for EVs with special features such as fault tolerant drives and smart grid connectivity.

3.2.2 Rail Transport

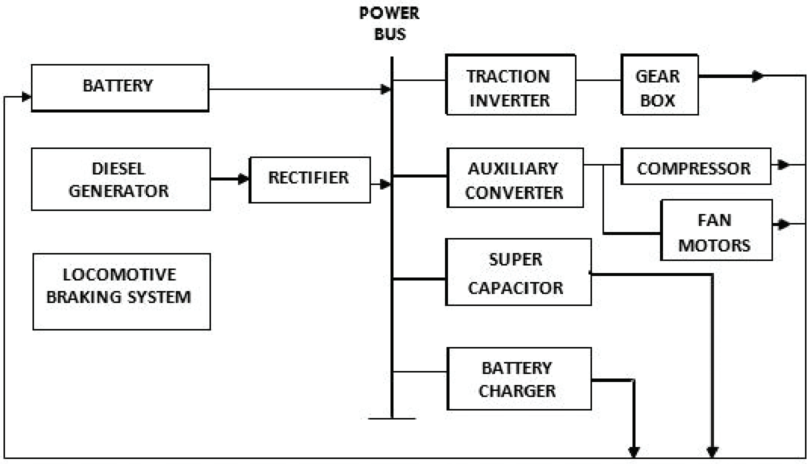
Railway is relatively a more energy-efficient mode of transport. Constantly rising energy prices have made it necessary to employ much more efficient drive technologies and state-of-the-art transmission systems. Important current developments are recovery of braking energy, latent heat accumulators for start-up of diesel engines and advanced engine technologies. Locomotives utilising multi-functional engines and generators are the major developments in recent years (C32). Railcar aerodynamics improvement, modular sandwich construction for making them lighter and use of aluminium or fibreglass composites are major advancements (C33). The compact freight car brakes with single lever power transmission, use of metal-composite hybrids for optimising the cargo container weight, steerable trucks with minimized rolling friction and fuel cell driven auxiliary power units are other notable engineering achievements. The high speed rail sector, which is experiencing rapid growth, needs cutting edge power technologies offering best energy to weight ratios, aerodynamic profiles and energy-efficient static frequency converters, vacuum cast coil dry type transformers and traction motors (C26) for wider global application. Breakthrough developments may occur in this sector.

Hybrid Diesel – Electric Locomotives

In the quest to find a relatively more energy-efficient mass rail transport in countries with heavily diesel reliant rail networks, hybrid diesel-electric locomotives offer real time energy-efficient opportunities. The CAETS Energy Committee considers this option as a forerunner to the introduction of a new range of hybrid technologies. International rail transport markets, which are growing at CAGR of 25%, are receiving them well. A

HYBRID DIESEL-ELECTRIC LOCOMOTIVES ARE FIRST PRIORITY FOR HEAVILY DIESEL RELIANT RAIL NETWORKS

Fig.4.4.4: Typical Diesel-electric Hybrid Locomotive Power System



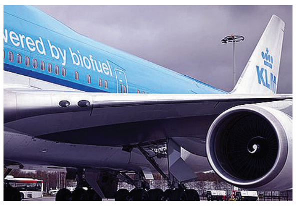
C26: ABB., Powering the World's High Speed Rail Networks, Background Information, www.abb.com/railway(2014)
C32: Energy Efficiency Export Initiative – Transport, A Study by the German Ministry for Economic Affairs and Energy, (2008)
C33: Transportation Energy Future Series: Potential for Energy Efficiency Improvement Beyond the light Duty Vehicle Sector, A Study by Argonne National Laboratory, IL, USA for US-DOE (2013)

MORE ADVANCES IN GEARED TURBO FANS, OPEN ROTOR ENGINES AND AERODYNAMICS ARE NEEDED TO MAKE AERO ENGINES HIGHLY ENERGY EFFICIENT.

diesel-electric hybrid locomotive employs a combination of electrical accumulator batteries and a diesel generator. Significant technology and engineering inputs have already gone into the development of advanced diesel engines, battery systems, regenerative braking, emission regulation devices and automation/control systems. **Fig.4.4.4** shows the hook-up of major components of a hybrid diesel-electric locomotive.

An important game changer on the hybrid technology front is the regenerative breaking option to effectively make use of the kinetic energy (KE) generated during breaking. Supercapacitors capture and store this energy. Hybrid propulsion retrofits are available for existing diesel engines. The new energy saving technologies include vehicle performance optimisation, better energy management controls, high energy density storage batteries, low energy climate control systems and performance improvement of traction motors.

3.2.3 Air Transport



Air transport has the potential to become more energy-efficient in the long run (C33). The current engineering advances include geared turbofans, improved compressors, advanced open rotor engines, aerodynamics that is more efficient and better uplifts through adaptive wings and use of elastic composites, which can make additional curvatures on wing surfaces. Technologists are exploring new lighter construction technologies with carbon composites or metal composite hybrids and optimal weight cargo containers. There have been significant engineering breakthroughs in developing large eddy breakup devices, hybrid laminar flow systems, innovative wing tip devices and control of boundary layer separation. Open rotor engines deliver significant fuel burn savings over conventional turbofans. Their major barriers are noise and safety. It is reported that the economic viability of geared open rotor engine will be established by 2017.

NOW, AIRCRAFT WINGS AND EXHAUST NOZZLES HAVE SMART MATERIAL OPTIONS TO MINIMIZE DRAG AND FUEL CONSUMPTION

Material Science and Engineering

High specific strength, lightweight and enhanced thermal capability are now available with composites, glass, carbon, Kevlar, ceramic and natural fibre based reinforcements and polymers. Though pure aluminium alloys are lightweight with high specific strength, aluminium lithium, high temperature (65°C+) titanium alloys and micro-structured nickel alloys are favoured. The emerging developments are in single crystal alloys for engine blades (C29). Ceramic matrix composites using reinforcing fibres are favoured in highly oxidising environment found inside modern aero engines. Nano composites made of clay, polymer or carbon or their combinations have improved mechanical properties. Materials have always been critical to aviation. Many new materials are coming online to meet the challenges of its higher heat, stresses and performance demands. For example, the Boeing 787 Dreamliner employs 50% composites, 20% aluminium, 15% titanium, 10% steel and 5% of other materials. There is a very strong value case for going forward with more advanced materials to achieve higher energy efficiency in aero engines. Rigorous safety requirements including protection against bird, fire, ballistic and lightning hits make material development extraordinarily challenging. The composites that are receiving attention for airframes are non-metallic fibres and glass embedded in plastic or epoxy matrix, which are high fatigue resistant. Composites are also available for low temperature engine applications. Emerging applications for composites are in the engine core.

In recent years, aircraft wings and exhaust nozzles have smart materials to minimize drag and fuel consumption. Efforts are also on to incorporate nanomaterials into their structures for self-healing and self-monitoring capabilities. The Airbus Industry is developing next generation materials for composite wing and hybrid metal-composite for reduced assembly time and for downsizing aero engines. Rolls Royce is supporting the development of dual microstructure nickel alloy discs, shape memory alloys, micro-electro mechanical systems (MEMs), active vibration control, electromagnetic actuators and high temperature electromagnetic valves. Another important development (C32) pertains to the optimisation of the weight and energy

C29: SBAC Aviation and Environment Briefing Papers: 8 Advanced Aircraft Materials., www.sustainable avaiation.co.uk/wp-content/uploads/advanced – aircraft....(2008)

GREEN AND ENERGY EFFICIENT AERO ENGINES HAVE TO ACHIEVE 50% CO_2, 80% NO_x AND 50% NOISE REDUCTION LIMITS BY 2020

consumption and use of renewable energy driven auxiliary power units.

Advanced Aero Engines

Air transportation sector is always sensitive to engine upgradation programmes with maximum stress on "higher and faster". A shift to "greener and energy-efficient" has now become necessary to achieve the targets of 50% CO2, 80% NOx and 50% noise reduction by 2020, set specifically for aero engines by the Advisory European Council of Aeronautics Research (AECAR). The heavily fossil fuel dependent aviation sector has been witnessing some remarkable technological advances in recent years with much better prospects than earlier for transitioning to lower carbon and renewable energy systems. The successful testing of biofuel and solar energy options for aero-engines are pathbreaking from the transition to LCE point of view. In July 2011, aircraft makers, engine manufacturers and oil companies approved biofuel for commercial use in aircraft. The IATA has found it feasible to achieve a 6% share of 2nd generation biofuels by 2020. These developments will have major impact on the advanced aero-engine development in the coming years.

The technology and engineering options employed currently in aero-engines are to achieve improved propulsion, thermal and aerodynamic efficiencies, performance improvement of engine components, more intelligent control systems and multi-fuel compatibility. The current propulsion efficiency improvement is directed towards achieving advanced turbofan architecture with emerging technologies on geared turbo fans and open rotor architecture. Thermal efficiency is dictated by the pressure ratio between the combustion chamber and the external environment, which is currently at 50 for achieving a thermal efficiency of 67%. Future engineering innovations will be to enhance it to 68 to achieve a thermal efficiency of 70%. There is need for engineering improvements in compression, combustor and turbine design, better thermal management of engine core and rationalisation of power off-takes. Aerodynamic efficiency improvement is possible through friction and lift drag reductions. Advanced airframe materials/structures and use of natural (NLF) or hybrid laminar flow (HLF) for minimisation of wetted areas and reshaping surface intersections are priority areas for engineering interventions.

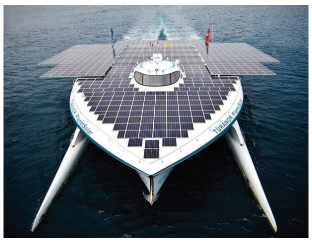
Impressive engineering developments have taken place in designing programmable logic controllers for aero-engines. Emerging options are memory mapped microprocessor controlled ignition systems and model-based advanced control systems for monitoring normal and deteriorating engine performances. The number of components in a jet engine is around 25,000. These have to be redesigned to work in future under more severe mechanical (>170 N/m^2), thermal (1,700°+C) and chemical (excess O_2, S and other pollutants) environments. Though multi-fuel compatibility is quite popular in military aircraft, it needs to be adapted for jet engines in civil aviation also. Interesting developments are emerging in novel propulsion architecture to facilitate the use of cryogenic biofuels.

3.2.4 Marine Transport

WORLDWIDE, 50,000+ COMMERCIAL FLEETS OF SHIPS CARRY 6+ BILLION TONNES OF CARGO PER ANNUM. NEW OPPORTUNITIES AWAIT THEM TO BECOME ENERGY-EFFICIENT.

Worldwide, 50,000+ commercial fleets of ships carry 6+ billion tonnes of cargo per annum. The Royal Academy of Engineering, UK published an excellent report in 2013 on "Alternative Methods of Ship Propulsion". It highlights the new opportunities before the marine transport sector to become energy-efficient. The shipping constituency compares well in CO_2 emission levels with other modes of transport. A range of energy options viz., diesel, bio-fuels, liquid NG, nuclear, solar, wind and hydrogen are available for this sector. Until recently, the fuel cell development in the marine field has been on a limited scale. Solar energy is a strong candidate for on-board auxiliary power generation systems. Majority of marine engines employ fixed, controllable and ducted pitch propellers. In addition, water jet hybrid, contra rotating, cycloidal and magneto hydrodynamic propeller configurations are used. Gas turbines have been used in specific marine applications and this can be propagated for high power density propulsion if high distillate grade fuels are employed in them.

Ships use high tensile strength structural steels including ferritic steels in large



SMART MATERIALS ARE FINDING FAVOUR IN SHIPS FOR VIBRATION DAMPING, THERMAL REGULATION AND IN SHAPE CHANGING HULLS FOR IMPROVED HYDRODYNAMICS.

MORE ADVANCED TECHNOLOGIES FOR SEAMLESS MULTI MODAL TRANSPORTATION WITH REAL TIME VEHICLE TRACKING AND INFORMATION SHARING

quantities. Composites exhibit excellent resistance to the marine environment. They find use in shaft overwraps, handrails, masts, propeller vanes, gear cases and valves. Lightweight plastics for ship super structure will necessitate less ballast and reduce fuel consumption. Nickel and cobalt based super alloys have major application in marine engines and gas turbines due to their reduced weight. Smart materials are finding favour in ships in recent years for vibration damping, thermal regulation and in shape changing hulls for improved hydrodynamics. Ships may soon be able to shed the unwanted accumulation of bacteria/marine growth with special coating materials that can wrinkle or change their surface in response to stimulus (pressure or electricity). Ships also need special materials such as polyester/vinyl-based structural adhesives and displacement-moulding compounds.

Advanced Marine Engines

Diesel engines have been the main workhorses in the marine transport sector for more than five decades now. In recent years, NOx and SOx reduction has become a major issue for commercial shipping. Technology solutions in terms of adjustable camshafts, variable inlet valve control, improved combustion, exhaust gas recirculation and two-stage turbo charging have received attention. Simultaneously, efforts have started to introduce next generation of intelligent diesel engines. Gas turbine marine engines, used by naval services, are also receiving attention for commercial marine transportation. Engineers have employed computational fluid dynamics (CFD) very effectively to enhance their cycle efficiencies by adopting new engineering concepts for intercooling, regeneration and reheating. Hybrid marine engines employing solar/wind/biodiesel as fuels are gaining popularity. A super conducting DC homo-polar motor is under development for marine transport systems. There are long-term prospects for nuclear propelled marine engines for super tankers and jumbo-sized cargo ships.

3.2.5 Multimodal Transport

The world "multimodal" refers to the integration of several transport modes within a specified region. It has the potential to leverage the advantages of its constituent transport modes to enhance the overall efficiency. A typical multimodal transportation system can cover airports, seaports, roads, railway, transit systems and bicycle/walkways to establish a seamless transport network for moving people and freight from point to point. When properly planned, designed, integrated and managed, it provides a safe, reliable, rapid, energy conserving, cost effective and environment friendly transport option for large sections of the population in big urban centres. Engineering developments in multimodal transport are mostly concerned with route planning, integration and management. There have been outstanding engineering advancements to make it a highly efficient seamless transportation option. Technological advances have been taking place in real time vehicle tracking and information sharing. Use of synergetic theory for coevolution of a multimodal transport system has been reported (C34).

Energy-efficient Multimodal Transport

The overall energy saving potential in multimodal transport emanates from public transport modal shifts, built-in incentives for renewable energy introduction, switchover to cleaner mix of component transport systems, short haul mobility with electric vehicles and transport sharing incentives. There is need for efforts to optimise the energy efficiency of a multimodal system. Energy factor was employed for the first time in USA in simulation model of a multi-modal transport system (C35) and China has initiated energy-related studies (C36). There is anticipation of more advanced technologies to achieve seamless cross-border continuity and interoperability of different transport modes.

3.2.6 Pipeline Transportation

Pipeline market will be worth US$ 14 billion by 2019. Pipelines transfer enough oil and

C34: F.Feng and Q.Zhang., Multimodal Transport System Co evolution Model based on Synergeti Theory, Discrete Dynamics in Nature and Society, Vol. 2015, ID 108926, 10 Pages (2015)
C35: LD Srinivas Peta, P.wei, D.sun; Incorporating Energy considerations its Multimodal Transport systems; TSIL Asilomer Workshop, Purdue University, USA, (2011)
C36: Donex, Study for the Management of Energy Efficiency under Whan tianhe Airport Multimodal Hub Project, RFP No.0733-155102463001, April (2015)

ENERGY REQUIRED TO OPERATE PIPELINE NETWORKS IS INCREASING STEADILY AND NOW RANGES FROM 40% TO 65% OF THE TOTAL TRANSPORT OPERATIONAL COSTS.

THE TOTALLY FOSSIL FUEL-DEPENDENT AIR TRANSPORT SECTOR WILL WITNESS MAJOR DEVELOPMENTS IN LARGE SCALE USE OF BIOFUEL AND SOLAR ENERGY OPTIONS.

petroleum products to fill 15,000 truckloads and 4,200 rail cars every day. Pipelines transport approximately 85% of oil and gas in the world. A total of 3.5 million km of pipelines are employed in 120 countries with the share of USA alone being 65%. Pipelines transport crude and refined petroleum, fuels such as natural gas and biofuels, sewage, slurry and water. Water is transported for drinking and irrigation purposes over long distances. China has recently launched the largest water pipeline project in the world to move 44.8 billion cubic metres of water/annum across the country for a total distance of 4,350 km. More than 210 systems with 480,000 km of pipeline transport natural gas in the world. There are nearly 2,400 compressor stations, situated at 80-160 km apart. More than 80% of these operate on natural gas as fuel and the rest by electricity. The oil pipelines employ centrifugal pumps placed 30-160 km apart. They use 15% of the energy consumed by the pipeline systems. A natural gas compressor station houses scrubbers, filters, compressors with their own power units, inter-stage and after coolers, energy shutdown systems and flow control and despatch systems. The oil pipeline terminals house tank farms, pumping sets, pressure reducing and metering stations.

A new dimension to pipeline transportation may be added through capsule transportation within underground (6 to 8 metres depth) pipeline networks (C50). One can deliver the capsules directly to the recipients through connection logistics, with computer controlled and aerodynamically optimised capsules. They are driven by electric motors at a speed of 36 km/h. The capsules can be propelled by hydraulic and pneumatic modes.

From design engineering perspective, the major types of flows encountered are gas, liquid, gas-liquid, solid-liquid, solid-gas and gas-liquid-solid flows. Their engineering is complicated due to multiphase flow patterns, thermal gradients, variable pressure drop and dynamic weight effects, seismicity and other factors (C37 to C39). Monitoring and control systems based on SCADA with advanced sensors help proper maintenance of long distance pipeline networks. Pig tracker technologies help in underground and underwater pipeline clean-up. Video surveillance, access control and alarm systems are employed for their security. The energy required to operate the pipeline networks is increasing steadily and now range from 40% to 65% of the total operational costs. It is also contributing to increased GHG emissions. Amongst pipeline transportation systems, natural gas pipelines (480,000+kms) report energy consumption regularly. In 2009, it was of the order of 0.3 billion MWh for transporting 318 billion tonne-miles of gas (C40a). Of this, 72% was in the form of natural gas. There can be better energy efficiency through waste heat recovery, upgradation of compressor efficiencies and increased part load efficiency (C41).

3.2.7 Intelligent Transportation Systems and Communication Networks

Intelligent transportation systems provide innovative services to all modes of transport in terms of telematics, traffic management and smarter use of transport networks. In case of road transport, these employ intelligent technologies for vehicle navigation, traffic signal control, freight management, speed cameras, vehicle number plate recognition, security CCTV and parking guidance systems. Realising the future importance of traffic congestion management, high-tech traffic controllers equipped with dynamic messaging signs and technically advanced traffic signals are being developed (C42). Such systems require collection of real-time

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C37: S.A.Hosseini et al., Considerations in Designing Multiphase Flow lines., Pipeline and Gas Journal., 239(8), August (2012)

C38 a): SK Lahiri and KC Ghanta, Development of ANN Correlation for Prediction of Pressure Drop of Slurry Transport in Pipelines., International J Math Sci & Engg Application 2(1), 1-21 (2008)

b): SK Lahiri and KC Ghanta, Computational Fluid Dynamics Simulation of Solid-liquid Slurry Flow in a Pipeline., Hydrocarbon Processing, May 2009

C39: ASME, Pipeline Transportation Systems for Liquid Hydrocarbon and other liquids., ASME Code for Pressure Piping, ASME B31.4-2007

C40 a): US-DOE Commercial Trucks, Aviation Marine Modes, Rail Roads and Pipelines and Offroad Equipment, Transport Energy Future series study by Argonne National Laboratory, USA (2013)

b): Intelligent Diesel Engines., https://en.wikipedia.org/wiki/Intelligent_Diesel_Engine

C41: A.Buretto et al, Energy Efficiency Improvement in Pipeline Transportation: Focus on Waste Heat Recovery, Pumping and Compression Efficiency and Site Date Management, A Paper presented at the 7th Pipeline Technology Conference, Berlin, Germany 8-10 June (2015)

C42: NEMA, Energy Efficiency and Economic Growth Intelligent Transport System, www.nema.org/policy/Documents/Energy - Efficiency and Economic Growth (2011)

C50: Cargocap, Automated Underground Transportation of Cargo, www.cargocap.com

A COMBINATION OF NEW APPROACHES UNIQUE TO RESPECTIVE TRANSPORT CONSTITUENCIES NEED TO BE ADOPTED TO GIVE A BIG BOOST ENERGY AND EMISSION REDUCTION.

traffic information to ensure physical integrity and safety of existing roads. LED technology is favoured for road signals and automobile lighting in several countries. The growing challenges for freight logistics with regard to just-in-time philosophy has increased competition between freight/cargo agencies handling all modes of transport. Application of satellite and wireless communication and information technologies has enabled introduction of advanced transport and fleet telematics systems to evolve computer-based real-time decision support.

3.2.8 Overall Findings from Technology and Engineering Review

In order to provide a big push to energy and GHG emission reduction targets of 2030 in the transportation sector, a combination of approaches, many of which may be unique to their constituencies, need to be adopted. The driving forces necessary for introducing new technologies have to be set in motion through policy and regulatory interventions touching fuel change, engine efficiency, transport modal shifts and efficiency of traffic management.

1. Although LDVs are reliable and environment-friendly with reference to current emission regulations, they have to meet higher performance standards in terms of their engine fuel efficiency and ability to use CO_2-neutral energy. The MDVs and HDVs, on the other hand, are predominantly diesel energy driven and the first transition to natural gas or biofuels or hybridisation is of high priority. The electrification of road transport vehicles is a game changer with high positive environmental impact.
2. Hybrid diesel-electric locomotives are vital in rail transportation for introducing more energy-efficient systems in developing countries with rail networks that are heavily reliant on diesel engines. Use of regenerative brake systems and super capacitors will witness greater energy efficiency in locomotive engines.
3. Totally fossil fuel-dependent air transport sector will witness major developments in large-scale use of biofuel and solar energy options. Solar is a long-term option, whereas biofuel is a medium-term proposition with plans to employ a 50% bio and jet fuel blend. Aero-engine technologies will undergo suitable upgradations for their commercial realisation. Efforts to improve propulsion, thermal and aerodynamic efficiencies and performance of more than 25,000 engine components are on the right track.
4. The marine transportation sector has successfully demonstrated the feasibility of advanced diesel engines, gas turbine and hybrid solar/wind/biofuel technologies. Their commercialisation is the next logical step. Technology advancements are on the anvil in intelligent engine controls and electrical and nuclear propulsions for large ships.
5. Though multimodal transport systems have inherent energy efficiency, there is scope for energy optimisation.

ENERGY-EFFICIENT HYBRID ENGINES ARE GAINING PROMINENCE IN ALL TRANSPORT CONSTITUENCIES AS A TRANSITION OPTION.

Capacity Building in Hybrid Transport Systems

The technology and engineering review presented in Section 3.2 has shown that energy-efficient hybrid engines are gaining prominence in all constituencies of the transportation sector. These engines integrate two or more energy resources in the same system to overcome performance limitations inherent to either of them in terms of energy efficiency, reliability, emissions and cost-effectiveness. They are likely to create new market opportunities for the low carbon energy regime.

From an engineering perspective, the design and development approaches employed in hybrid systems are substantially different from the conventional systems since these feature two power systems, which have to work independently as well as together. There is much more electrical and electronic content in them. Hybrid systems employ many complex components such as electric motors, inverters/converters, high voltage batteries, capacitors, controllers and a variety of sensors. These systems also require a range of numerical computational tools (for e.g., 3D computational fluid dynamics (CFD) and finite element simulations) to simulate their

ACADEMIC AND R&D INSTITUTES NEED TO BE SENSITISED AND INVOLVED TO DEAL WITH CHALLENGES OF EMERGING HYBRID OPTIONS.

performance. There is need for specialised engineering expertise for hybrid system design and integration, establishing robust control systems, fault diagnosis, hybrid transmission and assembly systems, electromagnetic compatibility, smart grid connectivity, etc.

The CAETS Energy Committee advocates the need to create major infrastructural facilities in the developing countries to facilitate R&D for hybrid technology adaption, testing and demonstration on a larger scale during the transition to LCE. Laboratory and pilot scale engine test beds, control instrumentation for real-time monitoring of a variety of hybrid architectures, cyber infrastructure for data processing, plug-in electric modules, online and offline performance measurements and verification tools, power electronic systems including battery charging infrastructure have to be established. Academic and R&D institutes need to be sensitised and involved to deal with challenges of emerging hybrid options.

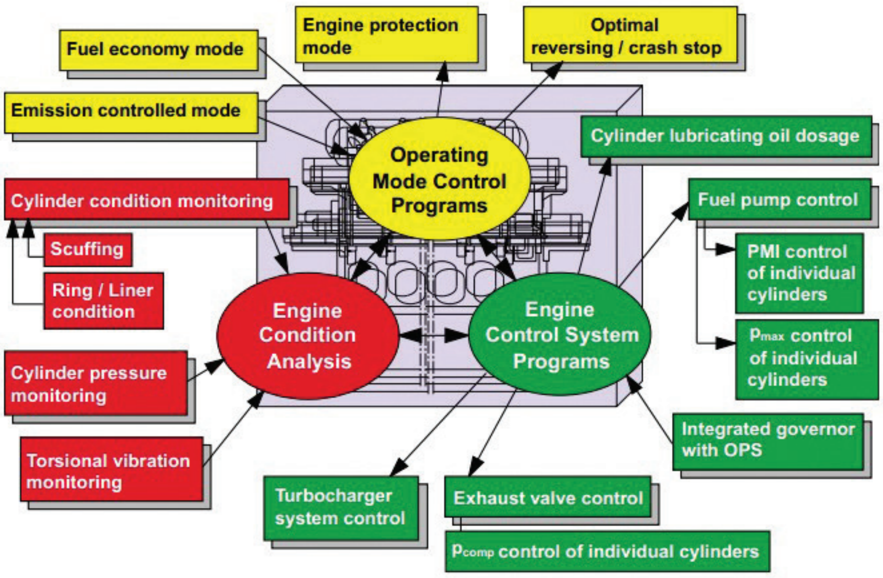
Role of Measurement and Verification Engineering (M&VE)

M&VE plays a crucial role in developing advanced vehicle engines. The focus is on measurements to assess the changes in fuel consumption and GHG emission from the candidate engines. Verification relates to third party evaluation of the efficacy of the developed options. In case of electrical vehicles, the electrical load impacts the entire distribution systems. Power quality, communication with charging units, venting and power characteristics of batteries and allied parameters have to be measured. The advanced LDVs, MDVs and HDVs require engine and chassis dynamometer checks for fuel consumption, gravimetric and volumetric fuel efficiency evaluation and rolling resistance.

The CAETS Energy Committee has noted the special measurement and verification engineering requirements of hybrid transport systems that may not necessarily comply with any particular protocol. These features include power breakup between battery and conventional power generators and monitoring their status during switchover to recharging mode, evaluation of regenerative breaking and engine responses to power load changes. The committee has noted in the case of intelligent engines, the need to develop a set of harmonised guidelines. The committee has noted the need to involve eminent institutions for evolving both top-down and bottom-up M&V protocols with appropriate template documents in several non conventional cases. Fig.3.2.8 shows the measurement engineering needs for intelligent control systems for marine engines.

MEASUREMENT AND VERIFICATION ENGINEERING RELEVANT TO HYBRID TRANSPORT SYSTEMS IS A PRIORITY AREA.

Fig.3.2.8: Measurement Engineering Demands from Intelligent advanced marine engines



Reproduced from Ref: C40b

Multidisciplinary System Design Optimisation (MSDO) for Transport Vehicle Engine Development

The transport vehicle engines are complex multicomponent systems requiring multidisciplinary engineering knowledge for their design and development. The CAETS Energy Committee sees an opportunity for MSDO techniques to assist in the design of advanced engines, which have to be globally competitive in terms of mechanical performance, energy efficiency and life cycle cost. The MSDO employs appropriate optimisation methods by considering the interactions between the system component functions. The MSDO has enabled the introduction of blended wing body concept in Boeing aircraft. From design optimisation point of view, transport vehicle engines are highly nonlinear. In the advanced engines, driving units, gear ratios, time of acceleration/deceleration and velocity while turning have to be simultaneously optimised by employing evolutionary algorithms with energy consumption as the prime objective function.

FROM DESIGN OPTIMISATION POINT OF VIEW, TRANSPORT VEHICLE ENGINES ARE HIGHLY NONLINEAR.

3.3 Outstanding case studies of energy-efficient transport systems and lessons learnt

The CAETS Energy Committee has noted some of the outstanding global efforts reported for making transportation systems more energy-efficient. These are highly inspiring for the engineering community to emulate them. This section seeks to capture these developments.

3.3.1 CNG Revolution in New Delhi, India

For many years now, public transport in developed countries uses CNG. This case study focuses on its use in a large developing country such as India for transitioning to LCE in a highly populated metropolitan city.

During the 1990s, atmospheric pollution levels in New Delhi, with a population of around 20 million with a density of 9,200 persons per square km, were dangerously high. The city occupied the fourth place in a list of 41 world's most polluted cities. Vehicular emissions accounted for 70% of the air pollution. In a display of timely judicial intervention., the Supreme Court of India in 1998 ordered the public transport system to switch over to a cleaner fuel. Working in tandem, the Delhi Government enforced necessary regulations to switch over to CNG by 2002. A comprehensive action plan followed to set up the necessary infrastructure for achieving such a major transition. (C43, C44). Since India did not have a robust and widespread CNG bottling and distribution infrastructure, Delhi faced number of technological challenges while implementing the CNG programme. The heavy vehicle transport industry had to adapt and indigenise the CNG kit for vehicles. Pollutants like CO, NO_x and SO_x had to be simultaneously addressed through catalytic converters. Establishment of more than 100 CNG refuelling stations in a short span of time with 60% of them having online connectivity was a major achievement of the public sector oil and gas companies. The local industry was encouraged to manufacture storage cascades (20-25 MPa), compressors and related accessories, apart from CNG kits for vehicles. By 2008, 3,500 buses, 12,000 taxis, 65,000 auto-rickshaws and 5,000 minibuses switched over to CNG fuel. The government also announced subsidies to encourage the private citizens to incorporate CNG kits in their vehicles to run on dual fuel mode. All these measures brought down carbon emissions by 72% and SO_2 emission by 57% by 2007. A study conducted by the World Wide Fund (WWF) for Nature found the policy adopted by the Delhi Government among the top 12 best policies in the world (C45).

Lessons Learnt

The key to success of the CNG programme for transport sector in Delhi was the legal obligation to use CNG in heavy-duty vehicles. The prompt government action to introduce emission norms, fixing a viable time schedule for conversion to CNG on a massive scale and imposition, for the

C43: N.Arsalan., Energy, Technology and Policy, Webber energy blog.wordpress.com (2010)
C44: S.Jain., Smog City to Clean Capital – How Delhi Did It?, Newsline, May (2004)
C45: N Hohne, J.Burak, K.Eisbrenner, M.Vieweg and L.Grieshaber, Score Cards on Best and Worst Policies for Green New Deal, WWF and E 3G (Nov 2009)

first time, penalties based on "polluter to pay" principle greatly accelerated the implementation process. The NGO community, concerned persons and groups affected by the large-scale pollution and a responsive political leadership played a significant role at various points of CNG implementation. The Delhi's CNG experience has shown that if critical instruments of a society including judiciary and government are supportive to the environmental cause and committed to large-scale implementation, the task of infrastructure development is not impossible to accomplish.

SUCCESS OF BIOFUEL INTRODUCTION IN AIR TRANSPORT DEPENDS ON CONCERTED EFFORTS OF MANUFACTURES, FUEL SUPPLIERS AND PROFESSIONAL BODIES.

3.3.2 Twin Initiatives to Reduce Fossil Fuel Dependence in Air Transport

Right now, there is no effective alternative to fossil fuels in air transportation sector. In recent years, two farsighted initiatives in this sector have shown new directions for air transport sector to adopt lower carbon energy options.

3.3.2.1 Successful Tests with Biofuels

Technological and engineering challenges involved in this initiative are development of an appropriate biofuel composition, conducting extensive engine compatibility tests, ground level engine and emission tests and aircraft flight trials. The IATA has been strongly supporting RD&D on alternative aviation fuels to achieve a 6% share of sustainable biofuels by 2020. This is in line with carbon neutral growth goal set by the aviation industry. A group of international airlines formed the Sustainable Aviation Fuel Users Group (SAFUG) in 2008 for development and use of aviation biofuels (C46). During 2008-13, there were 20 demonstration flights by seven commercial airlines from UK, New Zealand, USA, Japan, China and UAE, apart from US Navy, NRC, Honeywell and other agencies. A variety of aircrafts including Boeing 737, 747 & 777, Airbus 320, T-45, AV-8B, Bombardier Q400 and others participated in the RD&D initiative. Biofuels from coconut, Babassu, Jatropha, algae, camelina and waste cooking oil and their combinations were tested. During 2011-13, eight commercial flights were operated along European and Trans-Atlantic routes. The GHG emission reduction ranged from 60% to 85%. Encouraged by this outstanding success, the European commission and leading airlines and biofuel producers have launched a new initiative to achieve 2 million TPA biofuel production by 2020.

Lessons Learnt

DURING THE DAY, SOLAR CELLS RECHARGE FOUR LITHIUM BATTERIES (TOTAL 633 KG; 260 WH/KG) TO FACILITATE THE AIRCRAFT TO FLY AT NIGHT.

The success of the biofuel initiative was mainly the result of the concerted efforts of aircraft makers, engine manufacturers and oil companies for transitioning to LCE. The support provided by IATA by setting goals for aviation industry to become carbon neutral by 2020 and supporting R&D initiatives provided necessary momentum to the programme. NGOs have formed the SAFUG for attracting large funding required for this initiative from progressive commercial airlines, military agencies and equipment/instrument manufacturers. This pioneering programme has provided an alternative LCE fuel option to air transport sector for the first time in the world history.

3.3.2.2 World's first successful Solar Powered Flight

Solar Impulse 2 (managed by Solvay, Omega, Schindler and ABB) is the world's first solar powered flight with an endurance to fly day and night on solar power without any fossil fuel. The revolutionary single seater Swiss aircraft, with 72-m wingspan, 3.8 m3 cockpit and 2,300 kg weight is made of carbon fibre. It is fitted with 17,000 solar cells (135 micron thin) built on the wings, which provide power to four electric motors of 17.5 EV each. During the day, the solar cells recharge four lithium batteries (total 633 kg; 260 Wh/kg) to facilitate the aircraft to fly at night. The aircraft had already undergone rigorous testing after 12 years of research and development.

It embarked on a round-the-world flight between March and July 2015 to cover 35,000 km in 25 flight days. By 10 March 2015, the aircraft successfully flew from Muscat (Oman) to Ahmedabad (India) by covering a distance of 1,465 km at a speed of 180 km/h non-stop for 16 hours at an

C46: Wikepedia, Aviation Biofuel, en.wikipedia.org/wiki/Aviation-Biofuel (2014) altitude of 7,000 metres. The trial is continuing. It is the longest ever distance travelled by a solar powered plane. This development will push the boundaries of engineering knowledge in the coming years towards renewable energy adoption by aviation sector.

HIGH SPEED RAIL IS A GAME CHANGER IN CHINA INSPITE OF INITIAL PUBLIC SKEPTICISM.

3.3.3 High Speed Rail System in China – The Game Changer

High-speed rail systems employ an integrated system of specialized rolling stock and dedicated tracks (C47). The first such system "the Bullet Train" began its operations in Japan in 1964. Since then France, Germany, China, Italy, Taiwan, Turkey, South Korea and Spain have developed high-speed rail systems to connect their major cities. In some of the countries (for e.g., France) high-speed rail system also offer freight services. The most successful high-speed rail systems in the world are Japan-JR Maglev (578 kmph) the French-TGV (570 kmph), the South Korea–KTX (427 kmph), the Taiwanese-THSR and the Chinese-Maglev (498 kmph).

China's HST revolution has been a socio-economic game changer. Since its introduction in 2007, daily ridership has increased from 0.24 million to 1.33 million in 2012 making its HST network the most heavily used in the world. China has the world's longest HST network of 10,000+ km in 2012. This is likely to reach 18,000 km level by 2015. Although China imported earlier HSTs from Alstom, Siemens, Bombardier and Kawasaki Heavy industries, the country simultaneously made efforts to acquire technological capabilities in HST signalling, track and support structures, control engineering and station design. Chinese technical teams also held patents on internal components design and development of train sets, which are operable at much higher speed (380+ kmph) as compared to overseas designs. Chinese also gained high-tech expertise in building ballast tracks, which can withstand high speeds and heavy loads. These technological successes provided the necessary confidence to Chinese teams to run world's only high-speed (430 kmph) train line since 2004. During early phase of HST, critics both in China and abroad had questioned the necessity of having an expensive high-speed rail system in a developing country. The government had justified its introduction for improving the economic productivity, stimulating the economy, cross-city economic integration, energy independence and environment sustainability and for developing the HST equipment industry. The Chinese HST services cost is significantly less than similar systems in the developed countries. It has forced the domestic airlines to slash airfares and has helped to upgrade the conventional railway system.

Lessons Learnt

The introduction of HST in China is a classic example of the long-term vision of a progressive government prevailing over the initial public skepticism to introduce an expensive HST system in a developing economy. The government made comprehensive efforts to mobilise more than US$ 150 billion through international debt financing, acquire the related foreign technologies and subsidised the HST travel to make it affordable to its people in the initial phase. Chinese engineering community facilitated the success of the programme by developing national level expertise on signalling, track and support structures, control software and rail coach construction.

PATH BREAKING EFFORTS ARE BEING MADE IN HYBRID FUELS AND SOLAR/ WIND ENERGY FOR MARINE TRANSPORT SECTOR TO TRANSITION TO LCE

3.3.4 Path-breaking Developments in Marine Transportation

The efforts to transition to LCE in marine transport sector was somewhat muted until 2005. The recent developments are indicative of some path-breaking efforts being made to adopt hybrid fuel and solar/wind energy options with low carbon intensity.

C47: UIC., High Speed Rail – Fast Track to Sustainable Mobility., International Union of Railways., ISBN 978-2-7461-1887-4., (2010) The reported developmental efforts in 2012 to employ a hybrid system with diesel powered Wartsila RT-Flex 96CK gas engine which can be run on waste-derived liquid bio-methane fuel are highly encouraging. A naval ship fitted with this system provides 60% of fossil fuel free operation. The engines were successfully tested (C48). World's largest solar powered boat, MS TURANOR, was launched in Germany on 31 March 2010. Propelled by a 60 KW electric motor, it sailed at a speed of 26 Km/h. In May 2012, it became the first-ever solar electric vehicle to circumnavigate the globe. The 31-metre boat is covered by 537 square metres of 93 KW solar panels connected to two magnet synchronous electric motors. There are 8.5 tonnes of lithium ion batteries on board the ship's hulls. It can carry four crewmembers. Interestingly, the boat is used for collecting waste materials on ocean surface (C49). The third major development is the successful testing of wind-biofuel hybrid engine system for a cargo ship at the University of Southampton's Wolfsan unit for Marine Technology and Industrial Aerodynamics in 2012 (C48). These three case studies may have significant influence on future engine technologies for the marine transportation to reach the LCE goals.

3.4 SUMMARY

The four major transportation sector constituencies viz., road, rail, air and sea transport have been experiencing different levels of growth, energy consumption and GHG emission abatement strategies due to variations in national transport policies, the driving forces available for infrastructure development and end use practices. Given the current energy utilisation trends, CO_2 emissions from the transport sector are likely to touch 9.3 Gt CO_2e by 2030 under BAU scenario. It is possible to bring it down to 6.8 Gt CO_2e by 2030, through rapid deployment of energy-efficient and emission reduction measures. They include development of more energy-efficient transport systems, transport demand management through modal shifts and multimodal transport options. The techno-economic trends of GHG emission abatement have shown that the social costs of emission reduction are low but the implied capital costs are likely to be high. Though transportation sector currently relies heavily on fossil fuels, there are definite indications of its constituencies moving towards lower carbon energy regime.

The CAETS Energy Committee has assessed the sensitivity of the current regulatory framework to promote energy-efficient systems since most of these are emission reduction driven. The committee has felt the desirability of formulating regulations with the twin objective of promoting energy efficiency and emission reduction preferably under technology neutral conditions.

The committee has reviewed the technology and engineering options for developing energy-efficient systems in all constituencies of the transportation sector. It has identified energy-efficient light duty vehicles, hybrid electric-diesel locomotives, advanced aero and marine engines and new multimodal transportation technology and engineering interventions to meet energy and emission reduction targets set for 2030. Although LDVs in road transport sector are reliable and environment-friendly as per present day standards, they need improvement in terms of engine fuel efficiency and ability to use CO_2 neutral energy. The hybrid diesel-electric locomotives for rail transport provide the best solution for countries with diesel-reliant rail networks. Adoption of biofuel for advanced aero engines and achieving multi-fuel capability by them are high priority areas. Adoption of gas turbine and hybrid electric-biofuel compatible engines in the marine transport sector has to be high on its energy saving agenda. Energy optimisation in multimodal transport systems needs engineering solutions.

Without pipeline transportation, the future of global economy will not be stable. It is unquestionably the safest and most economical way for the mass transportation of liquids, gases and to some extent solids. Pipelines will continue to play an important role even if the energy markets transform to a lower carbon economy. The engineering focus will be on increasing of operating pressure, energy savings, CO_2 emission reduction, mitigating environmental impact during their construction, life extension of ageing pipelines and application of modern control technologies.

C48: PANOLIN, 100% Fossil Fuel Free Cargoship, www.ship-technology.com/features/feature fossil-fuel-free-environment, 16 August (2012)
C49: BAYERS 99, TURANOR Planet Solar, en.m.wikipedi.org/wiki/TURANOR-Planel Solar (2013)

CHAPTER 4

FINDINGS ON TECHNOLOGY AND ENGINEERING OPTIONS FOR BUILDING AND TRANSPORTATION SECTORS

CHAPTER 4

4.0 Preamble

The CAETS Energy Committee has conducted a technology and engineering review of various options for transitioning to low carbon economy for the building and transportation sectors, as presented in Chapters 2 and 3, with the fellowship of CAETS Member Academies as the target audience.

It has clearly recognised the complexities and opportunities in transitioning to the LCE regime in the two sectors. Many innovative technologies and new engineering options are required to achieve higher energy efficiency and lower greenhouse gas (GHG) emissions. The transition can stimulate a host of new options for partial or total fuel decarbonisation as well as for higher energy utilisation efficiency in building and transportation sectors. Integrating the efforts for large scale deployment of mature technology and engineering options in the existing infrastructure is found to be a formidable task. Globally, there is a near unanimity that achieving energy efficiency in working systems will be a key driver for fuel decarbonisation. This is very much evident from the rapid strides being made in the development of hybrid systems where more than one energy resource is employed to overcome energy-efficient performance limitations inherent to either of the systems. Choices to be made in fuel decarbonisation and energy efficiency enhancement, however, differ among countries depending on commitments which drive policies, maturity of relevant technologies, technoeconomic feasibility and demonstrations.

This chapter attemps to present the major findings of the CAETS Energy Committee to help sensitise policy makers on technological issues and recommended initiatives to realise their potential. They are tabulated in terms of the current priorities, technology and engineering options and emerging developments. Specific information on international developments and factors contributing to the favourable or unfavourable environment are presented as preamble to each table. At the end, initiatives to realise their full potential are briefly discussed.

4.1 Building Sector

Achieving higher energy efficiency has been a focus area in the building sector since 1990s in developed as well as fast growing developing countries such as China and India to support sustainable sectoral development as well as social equity. The market development for energy-efficient systems in the case of new buildings is relatively more practised as compared to the energy-efficient retrofitting of the existing buildings which varies in magnitude for high and low end structures.

4.1.1 Technology Priorities and Emerging Options for Energy Efficiency in Buildings

Table 4.1.1, presented in 4 sections, identifies the current priorities in energy and emission reduction, developments in advanced materials, their regulatory aspects and options for overcoming technology related barriers. The factors, both in favour and against energy-efficient technologies are given due attention.

i. New Buildings to be Energy Compliant by 2030

Nearly 2 billion new buildings are expected to be constructed globally by 2050 with a floor area of 235 billion square metres (90% residential) costing around US$ 3.7 trillion. Energy consumption in commercial buildings has been increasing by 1% per annum while on-site electricity demand has increased by 3% per annum in recent years. More than 25,000 passive energy buildings existed till 2010. Globally by 2030, substantial number of new residential buildings have to be passive energy-efficient and new commercial buildings net zero energy-compliant, with onsite renewable energy generation facilities to compensate their energy demand. This also brings in the need to redesign the electricity distribution grids with the ability to accept distributed renewable energy power inputs including those from built-in solar collectors from buildings to make them net positive energy-efficient subsequently.

Item 1.1 of Table 4.1.1a suggests the current priorities and emerging options for energy and emission reduction in buildings. They are based on the findings of the CAETS Energy Committee.

Table 4.1.1a: Current Priorities and Emerging Options for Energy and Emission Reduction in Buildings

Item	Current Priorities	EMERGING TECHNOLOGY OPTIONS (2030)
1.1 New Buildings (ES: 1.8 to 2.5 ER: 0.4 to 0.5)	• Energy-efficient building envelopes	• Passive (residential) and net zero energy (commercial) building targets • Smart and solar envelopes • Radiant chilled beam systems
	• Energy-efficient HVAC systems	• Part load performance driven • Heat pumping, thermostating and adsorption chilling • Displacement ventilation • LED & daylighting • High performance thermal storage • Hybridisation of energy sources (renewable-nonrenewable)
	• Advanced energy management systems (large building complexes)	• Energy analytics with real time controls • Big data and cloud computing for intelligent systems • Networking with smart grids
2.2 EXISTING BUILDINGS (ES: 3 to 6 ER: 0.35 to 0.7)	• Energy-efficient envelope retrofits	• Thermal performance survey of existing buildings • Reflective surfacing • Closed cell spray insulation • Smart facade and window retrofits
	• Energy-efficient HVAC retrofits	• Upgradation of coefficient of performance of buildings • Coupling solar thermal and photovoltaic systems • Variable speed drives • Micro gas turbines for combined heat and power systems (CHPs)

ES: Energy Savings in billion MWh/Yr by 2050
ER: Emission Reduction in giga t CO_2/Yr by 2050
HVAC: Heating, Ventilation, Airconditioning and Cooling Systems

ii. Integrated Design Strategy For Energy-efficient HVAC and Energy Management Systems

Numerous opportunities are available to improve energy efficiency of HVAC systems. An effective HVAC strategy has to rely on an integrated approach leading to reduced energy demand. The systems have to be part load performance driven with focus on minimisation of heat produced by lighting, appliances and human activity (Item 1.1 of Table 4.1.1a). Optimisation of temperatures and air distribution system with minimum pressure loss is necessary without compromising on space comfort and performance. Modern technological options should enable reduction in mechanical HVAC demand by at least 50% by 2050. Options such as targeted delivery or radiant cooling, displacement ventilation and adsorption chilling for air-conditioners are important. The market for advanced energy management systems for buildings, consisting of interlinked and networked control units, is poised to reach US$ 5.6 billion by 2020.

iii. High Priority for Energy-efficient Building Retrofits

Globally, an estimated 14 billion sq.m., of existing building space is expected to be retrofitted with energy-efficient systems by 2050. The existing rate of retrofitting is less than 2% of the existing buildings per annum. Green retrofits provide well-benchmarked upgrades for existing buildings with improved energy and GHG emission performance levels and enhanced natural light, air quality and human comfort. An enabling technology and market environment, effective project financing and strong delivery mechanisms have to be supported through the income generated by the energy savings over time. Energy-efficient retrofits can be provided separately for roof, wall, windows and basement. The CAETS Energy Committee highlights the need for professional engineers to understand the building structure and retrofit interactions more intensely to develop cost-effective and novel retrofit options in the coming years. It also stresses on the need to make energy-efficient retrofits for existing residential buildings a top infrastructure priority and the need to establish a strong incentive system to create compelling market opportunities for the global building industry. Item 1.2 of Table 4.1.1a highlights the emerging technology options for building retrofits.

iv. Energy Efficiency as a Driver of Change for Advanced Building Materials

CAETS Energy Committee has noted that the national level incentives and energy efficiency rating systems drive the discovery and development of advanced materials with specific surface, electrochemical, electronic, photonic or allied functions. They include special concretes, metal alloys, non-metals, composites, fibre reinforced and sandwich core materials, adhesives/sealants/bonding agents, coatings and magnetic, power electronic and nano particle based materials. Highly functionalised smart and interactive materials need to be designed ab initio on the basis of structure-functionality relationship. Their ageing mechanism needs a systematic study since their life span has to be extended beyond 50 years. The search for novel material solutions needs to be intensified by 2020 with scale up of their production and deployment to be achieved by 2025. It is expected that their base price in 2020 will experience 20-40% reduction by 2030 and 30-70% by 2050. Table 4.1.1b highlights the emerging material options in the building sector.

v. Redesigning the Regulatory Paradigm for Energy Efficiency

The key question for policy makers is whether the current regulatory paradigm needs to be redesigned to provide better support to transition of LCE initiatives. The CAETS Energy Committee recommends more progressive building energy and GHG emission rating systems, which will become a key instrument for large scale propagation of passive and zero net energy and emission technologies in the building sector. While notable developments in evolving energy ratings have taken place in case of new commercial buildings, the same cannot be said about the integrated energy and emission ratings/standards for new and retrofit residential and commercial buildings which are less expansive. The global markets are yet to factor energy efficiency into their decision making as compared to emission abatement. The residential energy improvement has been identified in several countries as a national building infrastructure priority with appropriate policies to promote and support new investments with a long-term revenue stream. Significant gaps are seen in evolving practical integrated energy efficiency and emission reduction rating systems for building retrofits. The Housing Energy Rating System (HERS) for new and retrofitted buildings, with focus on heating and cooling of indoor space, is a step in the right direction. It must be imperatively accompanied by appropriate emission reduction guidelines and incentives to be offered to millions of willing residential building owners. Table 4.1.1c highlights the current energy driven regulations and implementable actions.

vi. Technology Related Barriers and Overcoming Options

The CAETS Energy Committee is concerned that the technology related barriers have been inhibiting new investments in energy-efficient building technologies in developing as well as developed countries. These are less recognised since they do not stem from the usual administrative and market related actions. They occur due to technology utilisation policy deficiencies, regulatory uncertainties/inadequacies and lack of technical understanding. Table 4.1.1d identifies potential solutions to overcome these barriers. The large-scale global adoption of energy-efficient building technologies has to be supported by country specific policies, prescriptive measures, energy/emission ratings and codes, fiscal incentives and other means to overcome the technology related barriers. This will facilitate the energy-efficient building markets to grow more aggressively from current level of US$ 300+ billion to 600+ billion by 2030. There is often lack of vital information on the performance of energy-efficient technologies to change the energy consumption practices of consumers. The perceived risks of energy efficiency investments often create road blocks for decision makers. Technology related barriers are much more in the case of energy-efficient building retrofits. Lack of engineering measurement of their current energy performance, slow technology uptake by the dominant small scale enterprises and poor patronage to cost-effective innovations are most bothersome. Fiscal driving forces are very essential to provide momentum to energy-efficient retrofitting of existing buildings.

Table 4.1.1b: Advanced Materials for Energy-efficient Building Systems

Building Components	Application Areas	Emerging Material Options
2.1 Building Envelope	• Roof and Walls	• Radiant barrier sheathing • Insulating concrete foams
	• Insulation	• High R spray and nano foams • Vacuum insulation panels
	• Façade	• High reflectance coatings • Energy producing algae • Detoxicating titanium dioxide • Smart interactive materials
	• Windows	• Solar control and impact resisting glasses • Suspended particles for thermal /light control • Smart window materials
2.2 HVAC Systems	• Heating/Cooling	• Phase change materials for thermal storage • Thermoelectric materials
	• Ventilation	• Desiccants for energy recovery ventilation
	• Air Conditioning	• Liquid desiccants (lithium salts/halide salt solutions)

Table 4.1.1c: Building Energy and Emission Ratings and their Regulations

Item	Current Building Regulations/Ratings	Implementable Actions
3.1 New Buildings	• Regulations are mostly GHG emission control driven	• Large scale Implementation of current energy rating systems is the first priority
	• Energy rankings in vogue - EPBD (EU) - IECC (ICC) - ASHRAE 189 - ENERGY STAR (USA) - HERS (Residential) - NABERS (Australia)	• An integrated energy and emission reduction framework needs to be evolved for building envelope and HVAC units
3.2 Building Retrofits	• Energy rankings in vogue - ASHRAE 189 - HERS (Residential) - CBD (Australia)	• Mandatory energy performance improvement of existing buildings has to gain traction for developing large-scale deployable retrofit technologies • Advanced energy retrofit guidelines are needed for important types of buildings

ASHRAE: American Society of Heating, Refrigeration and Air Conditioning Engineers
HERS: Home Energy Rating System of EU
CBD : Commercial Building Disclosure Regulations of Australia
EPBD : Energy Performance of Buildings Directive
ICC: International Code Council
IECC: International Energy Conservation Code

TABLE 4.1.1d: Technology Related Barriers and Overcoming Options

Item	Major Barriers	Overcoming Options
4.1 New Buildings	• Lack of available and accessible information on new energy-efficient technologies	• Information campaigns by professional societies • Worldwide access for relevant web information • AEMS Software at affordable cost
	• High investment and operating costs of best technological options	• Capitalising energy efficiency investments • Tax restructuring for energy-efficient investments • Incorporating energy costs for mortgage underwriting
	• Weak policy and regulatory support	• Relevant, effective, flexible and clear cut policies • Incentivising carbon emission reduction • Specifying minimum energy performance standards
	• Slow technology uptake	• Improvement of skills and knowledge of site engineers • Consumer engagement with technology owners and propagators
	• Lack of system design approach	• Demonstration projects for new promising tools • Awareness campaigns amongst stakeholders
4.2 Building Retrofits	• Energy performance of existing residential buildings poorly measured	• Public funded energy surveys in existing building clusters
	• Lack of innovations leading to cost reduction	• Industry – academy sponsored R&D on innovations that make robust economic sense
	• Slow technology uptake by dominant players viz., micro and small enterprises	• Technology demonstration through public-private partnership
	• Insufficient fiscal driving forces for new technology uptake pertaining to lower carbon energy	• Energy efficiency driven feed-in-tariffs; variable municipal taxes; matching government grants

AEMS: Advanced Energy Management System

4.1.2 Initiatives to Maximise the Opportunities for Transitioning to Lower Carbon Building Energy Technologies

The overall observations of CAETS Energy Committee on implementable initiatives to maximise the potential of technology and engineering options are highlighted here:

i. Enhancing Energy Reduction Potential of Buildings

- Integration of energy-efficient technology and engineering options, as outlined in Table 4.1.1.a to d, have to be in conformity with passive/net zero/net positive energy concepts
- Increasing the amount of onsite electricity generation from lower carbon technologies
- Making energy-efficient retrofitting as a post-construction necessity for capturing low hanging energy fruits
- Stricter implementation of current energy rating systems and formulating integrated energy and emission rating regulations

ii. Road mapping and Direction Setting for Technological Transformations

- Clear identification of milestones with appropriate levels of energy and carbon reductions which are required for buildings under various environmental scenarios.
- Identification of portfolio of technologies pertaining to building envelope and HVAC systems needed over the short, medium and long horizons for bringing the necessary changes.
- Selection of a policy package that could catalyse and realise the ambitious and challenging targets based on past experiences and extended confidence.

iii. Accelerators for Deployment of Energy-efficient Technologies

- A menu of policy options along with the required technological support to leverage cost-effective options with real world achievables
- Promoting frugal technology options for generating cost-effective materials and energy-efficient options in emerging economies
- Human resource development through well conceived on-job training and entrepreneur development initiatives

iv. Cultivating Life Cycle Assessment Culture

Life cycle assessment culture is somewhat weak in the building sector. Stakeholders need to be aware of the long-term impact of their actions on energy and environment. This is a need to promote life cycle assessment culture much more strongly at the design phase of new buildings or before undertaking major retrofitting initiatives. Building owners, architects, designers and developers should have access to LCA tools along with up-to-date engineering literature on the methodologies involved and success stories.

v. Propagating the Inspiration Value of World's Most Energy-efficient Building Initiatives

There is no better way than to share the inspiration value of difficult to implement building retrofitting cases worldwide through engineering lessons learnt from these experiences. Their large-scale dissemination can inspire the market transformation, assist in forging new engineering collaborations and creation of new retrofitting value chains. More case studies are needed in energy-efficient building retrofits.

4.2 Transportation Sector

In order to provide a big push to energy efficiency and emission reduction initiatives in transportation sector, a combination of technology and engineering approaches, which may be unique to their constituencies have to be developed and adopted for achieving a smooth transition to LCE. Necessary driving forces in terms of appropriate policy and regulatory interventions are required for these initiatives to succeed. The CAETS Energy Committee has noted that the energy-efficient hybrid engines have gained prominence in almost all constituencies of the transportation sector. Hybrid engines have integrated two or more energy sources in the same system to overcome performance limitations of either of these. Engine manufacturers are able to create new market opportunities for the resulting lower carbon option when the newly introduced energy resource(s) is not mature enough for direct market introduction. The success and larger scale deployment brings in the need for new capacity building in hybrid engines and their accessories. The CAETS Energy Committee has taken note of the recent positive outcomes in fuel decarbonisation efforts being made in aviation and marine transportation sectors.

4.2.1 Emerging Priorities and Technological Options for Energy-efficient Transportation

Table 4.2.1 in five sections, along with the respective explanatory texts, identifies the current priorities, technology opportunity areas and emerging options in road, rail, air and marine transportation systems. The technical requirements in these transportation sectors are quite varied in nature and sometimes unique to a particular constituency.

i. `Avoid, Shift and Improve' Strategy for Sustainable Mobility Paradigm

The global GDP is expected to double during

2010-30 with an anticipated US$ 55 trillion investments in the transportation sector. The expected traffic growth till 2030 is 4.7% per annum for passenger aviation, 5.9% for air freight, 6% for marine freight and 2.3% for rail transport. Quality infrastructure is a key pillar for achieving international competitiveness in the transportation sector. The CAETS Energy Committee stresses the need to achieve energy and emission reduction in highly petroleum feedstock dependent transportation sector in all countries. The cost-effective technoengineering improvement of transportation vehicles and their engines to achieve 50% fuel economy by 2030 is extremely challenging but attainable if new technology uptake in all its constituencies is maximised with appropriate policy and regulatory support. The `Avoid, Shift and Improve' policy to minimise unnecessary travel, to encourage modal shifts and to improve vehicle engines contributes to CO_2 emission reduction significantly. Upgrading the traffic management systems is full of engineering challenges. While assessing the mitigation options on a large scale, it is essential to consider the life cycle GHG impacts. The multimodal approach to transportation has major influence on fuel efficiency of transportation vehicles. The CAETS Energy Committee considers the holistic approach as an essential feature of future transportation growth under the lower carbon economy regime. Table 4.2.1a shows the major findings of the committee with respect to energy and emission reduction options for various transportation systems and their supporting infrastructure and smart traffic management priorities.

ii. Pipeline Transportation to Establish itself more firmly as Fifth Transportation Mode

The modern era of technological advances has made it possible to use pipelines in much more diversified areas beyond gas and liquid transport. Transportation of solids through automated underground capsule transportation within the pipeline network is an emerging potential option. The energy consumed per unit distance per unit weight of products moved by pipelines is comparatively much less than rail, road and other transportation modes. There is a high potential for ultra deep water, CO_2, biofuel, shale gas and packaged goods transportation by pipeline. There are enough natural gas pipeline networks in the world today to reach the moon and back (3-5 times). With more than 3 million km of global pipeline networks and new investments in pipeline networks likely to exceed US$ 20 billion by 2030, the need for intelligent pipeline networks becomes a necessity. More engineering advances are anticipated in hydraulic, pneumatic and capsule in pipeline mode of pipeline transportation.

iii. Advanced Propulsion Technologies to Drive Future Changes in Road Transportation

The CAETS Energy Committee considers advanced fuel efficient propulsion technologies and fuel decarbonisation as the major drivers for change management in road transport sector. Llight duty vehicles (LDVs) consume more than 50% of the energy used in the transportation sector. While energy-efficient LDVs using IC engines with reduced GHG emission would cost 10-30% more, electric and fuel cell equipped LDVs may cost 25-30% more. The IC engines in LDVs will, therefore, remain the mainstay for several years to come. They are however, limited by their low thermodynamic efficiencies and advanced engineering interventions are needed to operate them close to the most desirable air/fuel ratios, use of opportunity type of controls and variable cam shift drive. More versatile high-strength light-weight materials and state-of-the-art power and accessory engineering are other high priority areas. The compression ignition engines employed in medium and heavy duty vehicles require more novel combustion engineering concepts and fuel switchover to CNG/LNG/Biofuels. CAETS Energy Committee considers the development of cost effective battery, electric, and H_2 fuel cells in LDVs as a leap forward in achieving renewable energy shift with significant emission reduction (Table 4.2.1b).

iv. The Surge of Innovations for Energy-efficient Rail Transportation

The Rail transport is far more energy-efficient than road and other modes of transport. Though the cost of electrification is high, electric locomotives are relatively less expensive to run. These consume 12.16 KWh to transport every kilotonne for a distance of one kilometre and have high priority in countries which are heavily diesel reliant for their rail transportation. The CAETS Energy Committee finds that the market for hybrid diesel-electric locomotives is growing at a compound annual growth rate of 25% and significant engineering advances have already been made in three-phase induction motors and their controls, electrical accumulator batteries and diesel generators (Table 4.2.1c). The emerging regenerative braking concept with super capacitors to capture and store the resulting kinetic energy will be an important game changer in energy-efficient locomotive technology. The new energy saving technologies will enable railways to employ optimised vehicle design, intelligent energy control systems, more efficient energy storage and improved traction motors to achieve further energy savings of 15-25%. The CAETS Energy Committee recommends the introduction of advanced turbo charged diesel engines in place of existing diesel engines to achieve fuel consumption of less than 188 gallons/KWh. Appropriate international mechanisms have to be evolved to help developing countries access modern technologies.

v. Advanced Engine Technologies for a Sustainable Aviation Paradigm

The aviation sector has set ambitious targets for itself to achieve 50% CO_2, 80% NOx and 50% noise reduction by 2020. This heavily fossil fuel dependent sector has been witnessing some remarkable developments towards biofuel use. Emerging engineering innovations pertaining to geared turbo fans and open rotor architecture for its engines may help to achieve thermal efficiency threshold of 70%. Advanced ignition controls based on memory mapped microprocessors will take these to the next level of automation. The CAETS Energy Committee sees new opportunities for employing smart materials in aircraft wings and exhaust nozzles and nano materials in air frame structures for drag minimisation and self-healing capabilities (Table 4.2.1d).

vi. Energy-efficient Marine Transport Systems

Worldwide 50,000+ marine fleets carry 6+ billion tonnes of cargo per annum. The shipping constituency compares well in CO_2 emission levels with other modes of transport. Diesel and residual oil fuelled engines have been the main workhorses of marine sector for more than 5 decades now. In recent years, NO_x and SO_x reduction has become a major environmental issue. Engineering options such as variable inlet valve control, two-stage turbo charging and exhaust gas recirculation provide near term solutions. A range of fuel options including biofuels, LNG, solar, wind and hydrogen are receiving attention in recent years. Hybrid engines employing solar/wind, and biofuels along with diesel are favoured as a transition alternative (Table 4.2.1e).

4.2.1a Current Priorities and Emerging Developments for Energy Efficient Transportations

Item	Current Priorities	Anticipated/Emerging Developments
1. Energy and Emission Reduction Options		
• **Road**	• `Avoid, shift and Improve' policy • Improving vehicle efficiency • Changing to lower carbon fuels • Recapturing energy losses	• Light weight energy-efficient engines with recycle options • Electricity/gas/biofuels (2nd generation)/fuel cells • Transport modal shift
• **Rail**	• Electrification • Advanced locomotive engines	• Energy-efficient traction power • Advanced hybrid engines with regenerative braking
• **Air**	• Advanced aero engines for extended range operations • Biofuel alternative and NO_x and SO_x reduction	• High propulsion, thermal and aerodynamic efficiencies • Multifuel compatible engines

• **Marine**	• Emission Abatement Options for existing ships • Significant shift to alternative energy sources	• Blended wing bodies (light weight engines) • Laminar flow technology • Advanced airframe and propulsion systems
• **Pipeline**	• Waste heat recovery • Upgrading compressor efficiency	• Part load efficiency driven approach • Capsule in pipeline and CO_2 transportation systems
2. Efficient Supporting Infrastructure		
• **Road**	• Multi lane highways • Vehicle-infrastructure communication for safety	• Automatic road traffic enforcement • Collision avoidance systems • Effective leveraging of road needs with communication engineering developments
• **Rail**	• High speed rail tracks • Efficient power grids	• Ballastless Track • DC/AC bifunctional operation
• **Air**	• Airports, runways and navigation systems • Ground support equipments	• Secured smart airport terminals • Touchless baggage processing and intelligent services/ systems
• **Marine**	• Seaports and container yards • Intermodal freight transportation systems	• Cruise ship and mega container ports • Mega container shipyards • Mobile offshore platforms
• **Pipeline**	• Compressor stations	• Line valve and blow down stations
3. Sustainable Multimodal Transport Systems		
• **Passenger**	• Maximising impact on socio-economic development • Intersection design/control • Seamless car-bus-rail-aviation-bicycle-walking	• Intelligent expert communication platforms • Plug in and play through cloud-based electronic logistics • Augmented reality concepts for interface design
• **Freight**	• Rail-truck-sea-air (containers) • Container handling equipment	• Real time control of freight networks • Radiofrequency based freight/fleet tracking
4. Smart Traffic Management Systems		
• **Road**	• Handling extreme heterogeneity/ rapidly changing topology • Realtime communications	• Vehicle adhoc networks (VANETS) and intravehicular sensors • Broadband wireless access • Cellular 3G/4G technologies
• **Rail**	• Increased throughput on existing infrastructure • Development of smart railway	• Predictive analytics for real time assets • Micro-macro technology for disruption management
• **Air**	• Always-on tracking of aircraft • Maximisation of safety, efficiency and usability	• Advanced radar tracker and server systems • Global air navigation satellite systems
• **Marine**	• Fast ship to shore communication • Traffic prediction	• Differential GPS technology • E-Navigation for dynamic route planning/QA
• **Pipeline**	• Traffic flow diagnostics • Big data analytics	• Online security and integrity tracking • Smart pigs

4.2.1b Current Priorities and Emerging Technology Options for Energy-efficient Road Transport Vehicle Engines

Item	Current Priorities	Technology And Engineering Option	Emerging Developments
Electrification of Light Duty Vehicles (LDVs)	• Plug-in Electric Vehicles (EVs) • Hybrid EVs (HEVs) • Plug in Hybrid EVs (PHEVs) • Tesla Cars • Battery Electric Vehicles (BEVs) • H_2 Fuel Cell Vehicles (HFCVs)	• Light Weighting • Magnetic synchronous and hybrid motors • Level II chargers (conductive/inductive)	• Carbon fibre structurals • Mould finished chassis • Level iii chargers • Asynchronus induction AC motors
Advanced LDV-IC Engines	• Advanced Fuel injection and ignition • NOx emission reduction • Adaptive control and after treatment • Thermal management • High speed direct injection diesel engines	• Variable compression ratio • Homogeneous charge compression ignition (HCCI) • Model-based controls • Waste heat recovery • Light weighting	• Spark ignited direct injection turbo (SIDIT) • Atkinson cycle • Common rail diesel injection (CRDI) engines • Multivalve engines with variable timing and lift
Advanced Medium and Heavy Duty Vehicles (MDVs/HDVs)	• Diesel to CNG/LNG/biofuel • Low NO_x in emissions • High volumetric efficiency	• Direct Injection/turbo charging • HCCI • High pressure direct injection • Multifuel injection	• Hybrid medium and heavy duty power trains • Aerodynamic drag reduction (20+%) • Low rolling resistance tyres
Advanced Materials	• Trade-oft between engine efficiency, light weighting and fuel consumption • Improved aerodynamics • Performance improvement of vehicle components	• High performance polycarbonates /PU foams • Carbon composites • Surface engineering for higher wear resistance	• Advanced coatings / films • Novel composites and layered materials • Nanoscale Inorganics

4.2.1c Current Priorities and Emerging Technological Options for Energy-efficient Rail Transport

Item	Current Priorities	Technology And Engineering Option	Emerging Developments
Electrification of Railways	• Enhancing traction power network capacity • Kinetic energy recovery during braking • Intelligent microelectronics and controls	• New engineering options • Regenerative braking system • Insular gate bipolar technology (IGBT) • Intelligent rail electronics	• Power quality conditioners • Ultra super capacitors for brake energy storage • Magnetic levitation technology
Hybrid Diesel Electric Locomotives	• Fuel flexibility and diesel use reduction • Hybrid traction propulsion • Improved engine performance	• Hybridization of energy resources • Regenerative braking system • Multiple diesel engines and three phase induction motors	• Fuel efficiency of 24+ km/ litre of diesel • Modern speed controls for induction motors • Hybrid traction propulsion retrofits
Advanced Version Diesel Engines	• Advanced reciprocating engine technology • Higher efficiency and more reliability • Fuel consumption: <188 gallons/KWH	• 4 stroke turbo charged engine with temperature control • Scalability with multiple engine systems	• Advanced diagnostics and prognostics • Static frequency converters • Dry type transformers • Adaptability to biofuels • Use of metal composites

4.2.1d Current Priorities and Emerging Technology Options for Energy-efficient Aero Engines

Item	Current Priorities	Technology and Engineering Option	Emerging Developments
Advanced Aero-Engines	• Greener and energy-efficient with 50% CO_2 reduction by 2020 • Improved propulsion, thermal and aerodynamic efficiencies • Model-based controls	• Advanced turbo fan and open rotor architecture; Blended wing Bodies • Friction and lift drag reduction • Natural or hybrid laminar flow for minimization of wetted areas	• Multifuel compatibility • Achieving thermal efficiency threshold of 70% • Improved thermal management and power offtakes • Memory mapped microcompressor based ignition control
Advanced Materials	• Enhanced temperature capability • Adaptive materials for reduced fuel burn/ emissions • Light weighting	• Composites with non metallic fibres in polymer matrix • Aluminium-lithium alloys • Dual microstructured nickel alloys • Smart materials embedded with nano particle	• Recyclable composites; ceramic matrix composites • Titanium alloys for 650+ oC service • Single crystal alloys • Self monitoring and smart material performance enriched by nano technology
Fuel Decarbonisation Efforts	• Biofuel • Solar energy	• Successful engine tests of biofuels • Long distance solar powered flight	• 2 million tpa biofuel by 2020 for aviation • Solar powered energy packs (ground)

Fuel Decarbonization Efforts

Table 4.2.1e: Priorities And Emerging Technology Options For Energy-efficient Marine Engines

Item	Current Priorities	Technology and Engineering Option	Anticipated/Emerging Developments
Advanced Marine Engines	• NO_x and SO_x reduction • Enhanced energy efficiency • Multifuel compatibility	• Variable inlet valve control; turbo charging • Gas turbine engines • Hybrid engines	• Intelligent engine drives • Magneto hydrodynamic propellers • Super conducting DC homopolar motors
Advanced Marine Engines	• Higher resistance to marine environment • Less ballast use • Smart operation facilitation • Special coatings for surface protection	• Special Ferritic steels • Light weight plastics • Nickel and cobalt based super alloys • Structural Adhesives	• Advanced materials for ship super structures • Materials for shape changing hulls • Minimize corrosion contributing marine growth
Fuel Decarbonsation Initiatives	• Shift from diesel • Renewable energy for onboard facilities • Efficient propulsion for jumbo cargo vessel	• LNG/Biofuel • Solar/Wind/fuel cells for auxiliary power units • Nuclear propulsion (long horizon)	• Solar powered small ships • Hydrogen as fuel (long horizon)

4.2.2 Initiatives to Maximise the Potential of Low Carbon Technologies

The large-scale deployment of a range of lower carbon and energy-efficient technologies as highlighted in Chapter 3 of this report and Table 4.2.1 a to e of this chapter for the transportation sector will lead to a more secure and sustainable energy future.

i. Enhancing Energy Reduction Potential of Transportation

The CAETS Energy Committee recommends the need to double the rate of energy efficiency improvement in this sector across all its constituencies. To achieve this objective, the following directions and priorities are recommended.

- Switching to lower carbon fuel alternatives has to be at the core of energy efficiency technologies in order to improve energy security and effectively address climate change
- Availing enabling support and establishing synergies with measures such as shifting travel modes, change in driver behaviour, employing fuel efficient tyres and other accessories and eventually driverless automobiles.
- Mobilising public-private partnership for research, development and demonstration (RD&D) of difficult to implement lower carbon energy technologies.

ii. Roadmapping and Direction Setting for Technological Transformation

- Cross-functional road mapping to link technological and non-technological activities, functions and information systems to achieve desired technological transformation in cost, quality and timeliness.
- Top-down direction setting to create necessary focus in organisations associated with technological transformation by embedding the roadmaps within their institutional charters.
- Bottom-up approach to get technicians and engineers at all levels to adopt innovative approaches to performance improvement of energy-efficient transportation systems.

iii. Accelerated Enablers for Deployment of Energy-efficient and Reduced Emission Technologies

- Transportation policies to be in tune with the emerging technologies. Such tailored technology policies coupled with stable and technology specific incentives including feed-in tariffs, tax incentives and loan guarantees have to be formulated and implemented by the government. They also need priority support and funding for new technological options which are transformational and disruptive in nature.
- Policy interventions and counselling are needed to encourage modal shifts. Simultaneously, efforts have to be made by the government to make public transport more attractive, create sustainable transport infrastructure and evolve proper land use policies.
- Facilitating shift of freight from energy intensive to less energy consuming transport modes.
- Linking new energy-efficient transport programmes with smart city, circular economy, nature based solution and other concepts for faster implementation.

iv. Identification of Priority Research Initiatives for National-Level Solutions

They include locally available alternative and hybrid fuel sources, semi-automation, special transportation options to reduce social/territorial inequalities, battery charging infrastructure, satellite-based navigational technologies and optimising inter-operability of multimodal transport systems.

v. Overcoming Technology-Related Barriers

Fossil fuel lock-in, distorted perception of technological benefits, technology transfer and infrastructure deficiencies are three typical technology-related barriers. There is need for the following.

- Assess their strengths and weaknesses in terms of measures to overcome them
- Provide special focus on making course corrections to provide more sustainable transport patterns
- Re-examine the barriers during alternative mitigation option assessments

- Encourage technology utilisation programmes through public-private partnership

4.3 CAETS Facilitation to LCE Initiatives

CAETS's recent efforts to constitute a standing energy committee with membership from 10 countries augurs well for upgrading its facilitation role in transition to LCE initiatives through its member academies. In association with international bodies on energy, environment, buildings and transportation, the CAETS can play a facilitator role in assisting its member academies to help their national governments in formulating plans for transitioning to LCE. By networking with its member academies, the CAETS can facilitate generation of new engineering knowledge on novel energy-efficient systems in building and transportation sectors through intercountry academic research endeavours. Facilitating advanced training to young engineers and joint initiatives by research leaders nominated by its member academies in centres of excellence of its member countries are other possibilities.

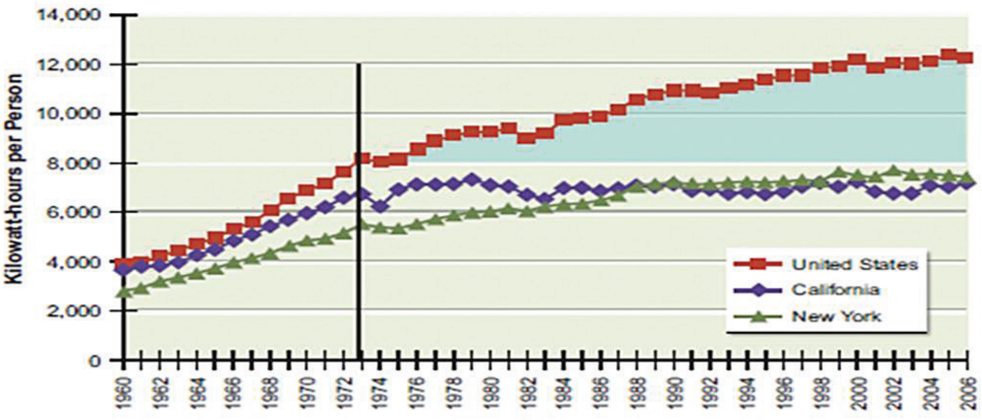
APPENDIX A

A1.1 Percapita Electrical Energy Consumption in USA

(by Dr. Maxime Savitz, NAE)

The most interesting case studies in the United States for accelerating deployment of energy efficiency and renewable energy supplies are largely in states where the combination of policy actions, resource availability, and economic conditions are supportive. For example, Figure A1.1 illustrates electricity use per capita from 1960 to 2006 in California, New York, and the United States overall. California maintained nearly flat per capita electricity consumption from 1975 to 2006. In 2006 its per capita use was about 40 percent less than that in the United States as a whole, although the two were nearly the same in the 1960s. The shaded wedge in the figure represents the growth in U.S. per capita electricity consumption since 1973. (Input from Dr. Mxine Savitz, NAE, USA)

FIGURE A1.1. Per capita electricity consumption (not including on-site generation) in California, New York, and the United States, 1960–2006; (Source: U.S. National Academies (2010) with information from U.S. Department of Energy, Energy Information Administration)

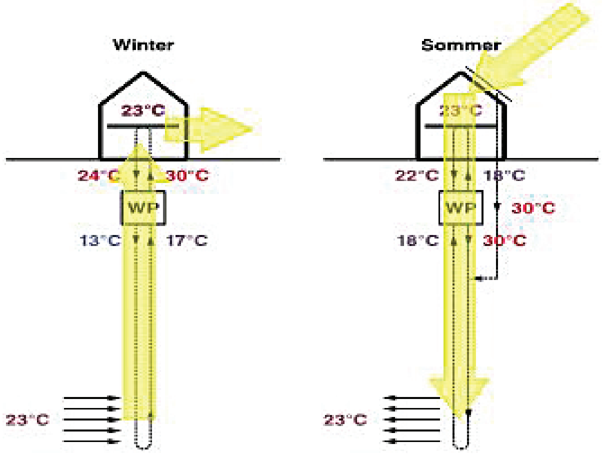


A1.2 Coupling External Thermal System to a Building – A Swiss Case Study

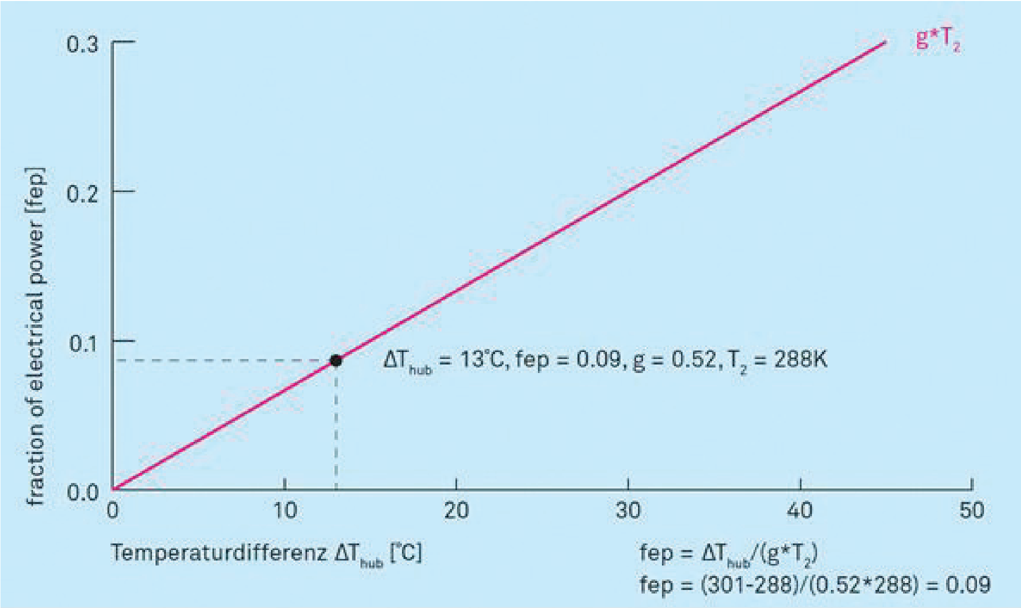
(by Dr. R Hugli and Dr. H Leibundgut of SATW)

In the latitude between the 42nd and the 60th degree north of the equator, buildings experience both winter and summer seasons of significant intensity. The indoor temperature conditions have to be maintained in a bandwidth between 20–25°C. The direction of the heatflux in and out of a building changes seasonally.

The 2sol principle (energy solaire avec stockage au sol) states, that the building is coupled to a second thermal system–the ground underneath the building–both oscillating with different frequencies and different amplitudes. In summer, heat is extracted out of the building (for cooling down the building) and is injected into the thermal capacity of the ground (heating the ground). In winter: heat is extracted out of the ground (cooling the ground) and injected into the building (heating the building).



According to the 2nd law of thermodynamics, the inverse process in winter does not work unless a heat transformation process is introduced between the ground and the heating system of the building. This process is the heat pump process which uses work (exergy).



The ZE-2sol principle was proposed by Prof. Dr. Hansjürg Leibundgut, ETH Zürich and is being proved in different buildings in Switzerland. The system is published in full detail on www.2sol.ch. Behind this principle there is a new philosophy. In traditional building design, operation in summer and winter are treated separately. Up to now the focus in building design for winter time was on isolation. Isolation is expensive and contains a lot of grey energy. Furthermore many of these highly isolated buildings tend to overheating in summer. With this new approach, excess heat of summer is stored for winter use. Consequently, the construction costs of the building structure are reduced and the operation costs in winter are lowered. Furthermore in winter a lot of expensive high quality energy (exergy) is saved which also significantly reduces carbon emission. This design principle can be applied to other regions in the world. Following the same physical principles, a ZE-lowEx system approach was investigated for tropical conditions in Singapore and Jakarta.

A1.3 Current Status of Transport Sector Constituencies

(by Dr. KV Raghavan, INAE)

A1.3.1 Road Transport

The present road transport systems in the world were established in the 20th century. According to the UN world urbanization prospects report, around 50% of world's population is currently living in cities which are getting bigger and more numerous. There are around 500 urban centres with more than 1 million population in the world. They have become the major organs of global economy with intercity transportation becoming an important development target. A complementary trend viz., sub-urbanization is also taking place. People, goods, services and information continually travel between urban centres forming the foundation of the present global society. The system of 2 and 3 wheelers, cars, buses and trucks interconnect these centres. The major drivers for rapid expansion of road transport system are significant population expansion in developing countries, hyper-urbanization leading to the formation of mega city clusters, globalization blurring the national borders and rapid spread of information and communications technologies. Several developing countries are facing the adverse consequences of an inefficient and inadequate road transport system. The current global road occupancy is more than 500,000 vehicle kms per roadway lane-km. In order to maintain these levels, globally 40 million paved lane kms have to be added by 2050. Out of these, the developing countries like China, India, Brazil and others have to add 35 million paved lane kms. The environmental impact in terms of CO_2 emissions of current road transport itself is quite serious and the future scenario will be quite alarming under business as usual condition. The future road transportation system has to be smart enough to address the main challenges of mitigating congestion and empowering the transport users with array of options, ensuring safety and security and eco-efficiency.

A1.3.2 Railway Transport

The Railway Handbook is published annually by the IEA. At present, nearly 50% of the world's railway lines are in North America and the European Union and China and India together have 12.5% of the world's railway lines. They move more rail passenger kilometers (61%) than the rest of the world combined. In 2006, nearly 240,000 kms of the world railway lines were electrified. High speed railway lines are constantly growing but they represent hardly 1% of total railway lines. High speed trains were introduced in Japan in 1964 employing specialized rolling stock and dedicated tracks. They operate on continuously welded standard gauge tracks with large turning radius. Many countries developed high speed passenger rail systems (250-450 km/hr) subsequently. They include France, China, Germany, Spain, Italy, Taiwan, South Korea and Turkey. Currently China has nearly half of the world's high speed lines in operation. Recently high speed rail systems are also being used for freight services, if necessary by employing dedicated freight corridors. High speed trains offer many advantages in terms of energy savings.

A1.3.3 Air Transport

Everyday, about 300,000 commercial, chartered and Cargo flights take off all over the world using a staggering amount of aviation fuel. They carry nearly 3 billion passengers per annum. Nearly 1700+ airlines operate a fleet of 23,000 aircrafts serving 3750+ airports through a route network of several million kms managed by 152 air navigation service corridors. The growth of world air travel has averaged approximately 5% per annum over the past 30 years. In general, annual growth in air travel has been about twice the annual growth in GDP of several emerging economies. The size of the industry is expected to double by 2030. The total revenue in global aviation sector has crossed USD 200 billion.

Civil aviation agencies in almost all countries regulate air travel as a public utility. The soaring energy consumption and fuel cost are two of the most worrying factors for the aviation sector. Cost cutting to maximise seats, acquiring more fuel efficient aircrafts and making air travel comparable to high class train travel are some of the efforts to sustain the industry amidst intense global competition. New partnerships, global alliances and cross border ownership of aerospace assets are altering the very complexion of the aviation sector. It is forecasted that Asia Pacific, Europe and Middle East regions will account for more than 90% of wide body and long haul aircrafts by 2030. An astonishing 65% of these aircrafts are expected to head to Middle East and Asia alone. New aviation countries in Asia Pacific region are expanding exponentially faster than those in American and European continents. The rising middle class of these countries are creating the real demand levels. In particular, Indian and Chinese impact on world aviation industry is quite substantial.

A1.3.4 Sea Transport

Marine transport provides the backbone for the international trade and is also a key engine for driving globalization. The sea transport sector is growing at 4 percent per annum with supplies outstripping demand. The global merchant fleet was 50,000 vessels strong in 2010 consisting of general cargo ships (30%), oil tankers (27%), bulk carriers (15%), passenger liners (13%) and container ships (9%). They carried 8.7 billion tons of goods in 2011 along all principal trade routes. Their sizes vary between 10,000 to 350,000+ dead weight (dwt). China, Japan and South

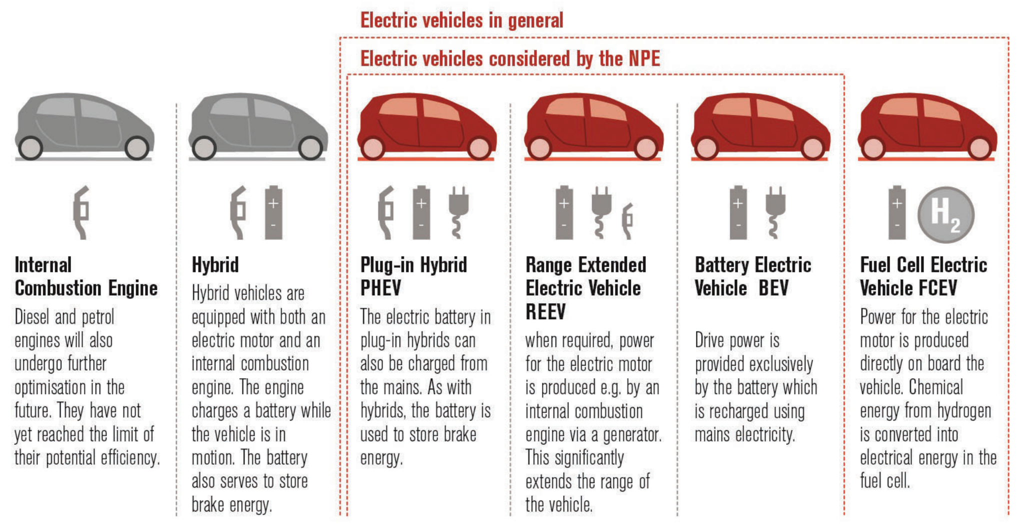
Korea together built more than 93% of tonnage delivered in 2011 in their shipyards. Nearly 33% of the world fleet are owned by the developing countries including India and China. The world container ports registered 6% annual growth to reach 600 million TEUs in 2011. The military use of sea transport and weaponry is one of the major components of national defence systems. A variety of ship forms, aircraft carriers and ground vehicles and installations are employed. Nuclear propulsion is employed for ships and submarine fleet by the world leading military establishments. Apart from military operations, coast guard in several countries employ a large fleet of naval vessels for their coastline protection.

A1.4 Future Fuel Strategy of Germany

(by Dr. F Behrendt, ACATECH)

The German Government's future fuel strategy makes an interesting study for other countries. Fig.A1.4 shows an overview of emerging LDV drive technologies with electricity and fuel cells playing a critical role. The optimization of IC engines will go hand in hand with continued development of low carbon based fuels from a variety of sources and production pathways as highlighted in Fig.A1.4.

Fig.A1.4: Overview of Emerging Drive Technologies



A1.5 Comparison of Japanese Car Performance

(by Prof M Ihara, EAJ)

The fuel performance of cars is not easily comparable due to differences in policy approaches, test drive cycles and units of measurements. The Engineering Academy of Japan (EAJ) compared the performance of cars registered in Japan in terms of relationship between fuel expenses and car weight, maximum power and torque. The details are presented in Figs.A1.5a, b and c.

Fig.A1.5a : Relationship between fuel expenses and weight (Cars registered in Japan)

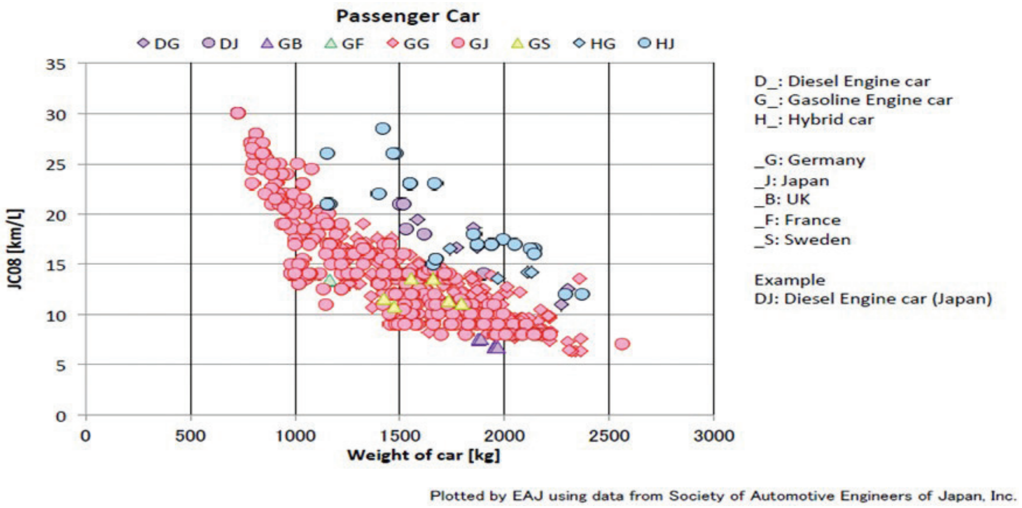


Fig.A1.5b: Relationship between fuel expenses and maximum power (Cars registered in Japan)

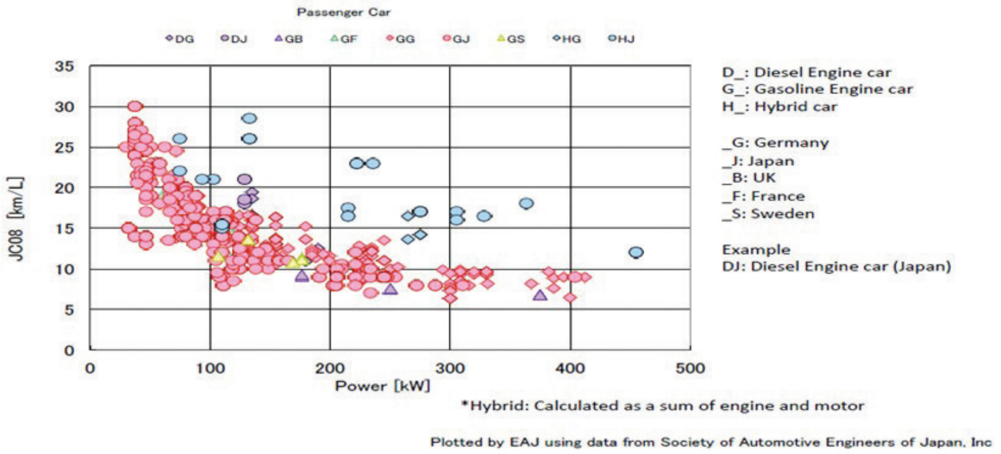
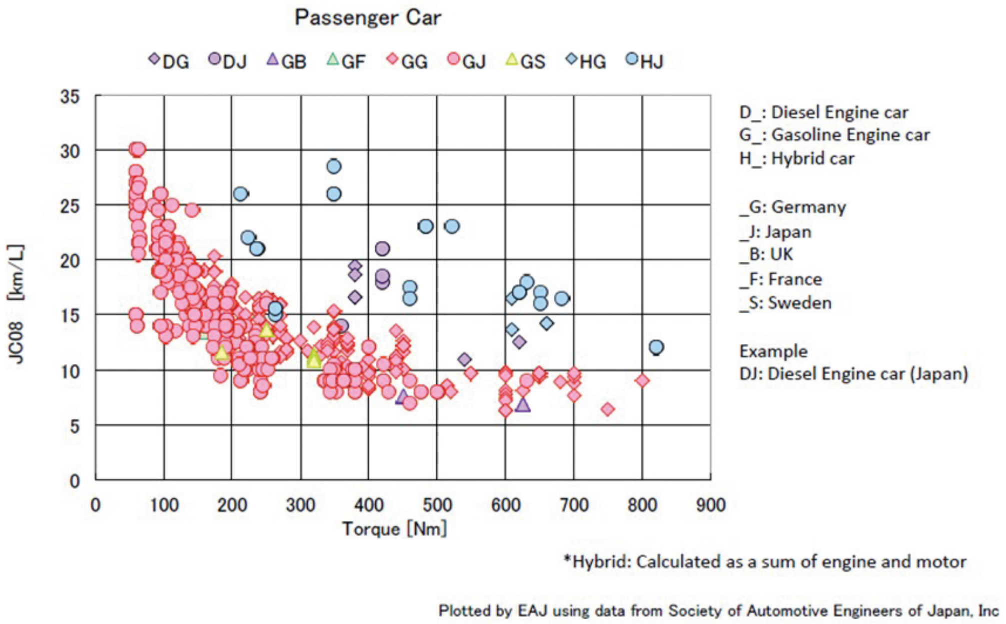


Fig.A1.5b: Relationship between fuel expenses and maximum power (Cars registered in Japan)



Notes

TRANSITIONING TO LOWER CARBON ECONOMY

Technology and Engineering Considerations in Building and Transportation Sectors

A Report for

The International Council of Academies of Engineering and Technological Sciences (CAETS)