

# **Development of fuel/engine systems - the way forward to sustainable transport**

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# Introduction - I

Transport is central to modern society and demand for transport energy is very large

Globally, it accounts for

- 14% of global GHG (CO<sub>2</sub>, methane and nitrous oxide) emissions, 20% of total energy use, 23% of CO<sub>2</sub> emissions
- Currently over 1.2 billion light duty vehicles (LDVs) and over 350 million commercial vehicles
- LDVs account for ~44% of global transport energy demand
- Transport is essentially driven by liquid fuels - high energy density, ease of transport and storage, extensive infrastructure
- **Over 4.9 billion liters each of gasoline and diesel and 1.2 billion liters of jet fuel each day. 105 TWh of fuel energy needed each day.**

Demand for transport energy is growing at an average annual rate of ~1 %

- In non-OECD countries

Petroleum and transport closely linked

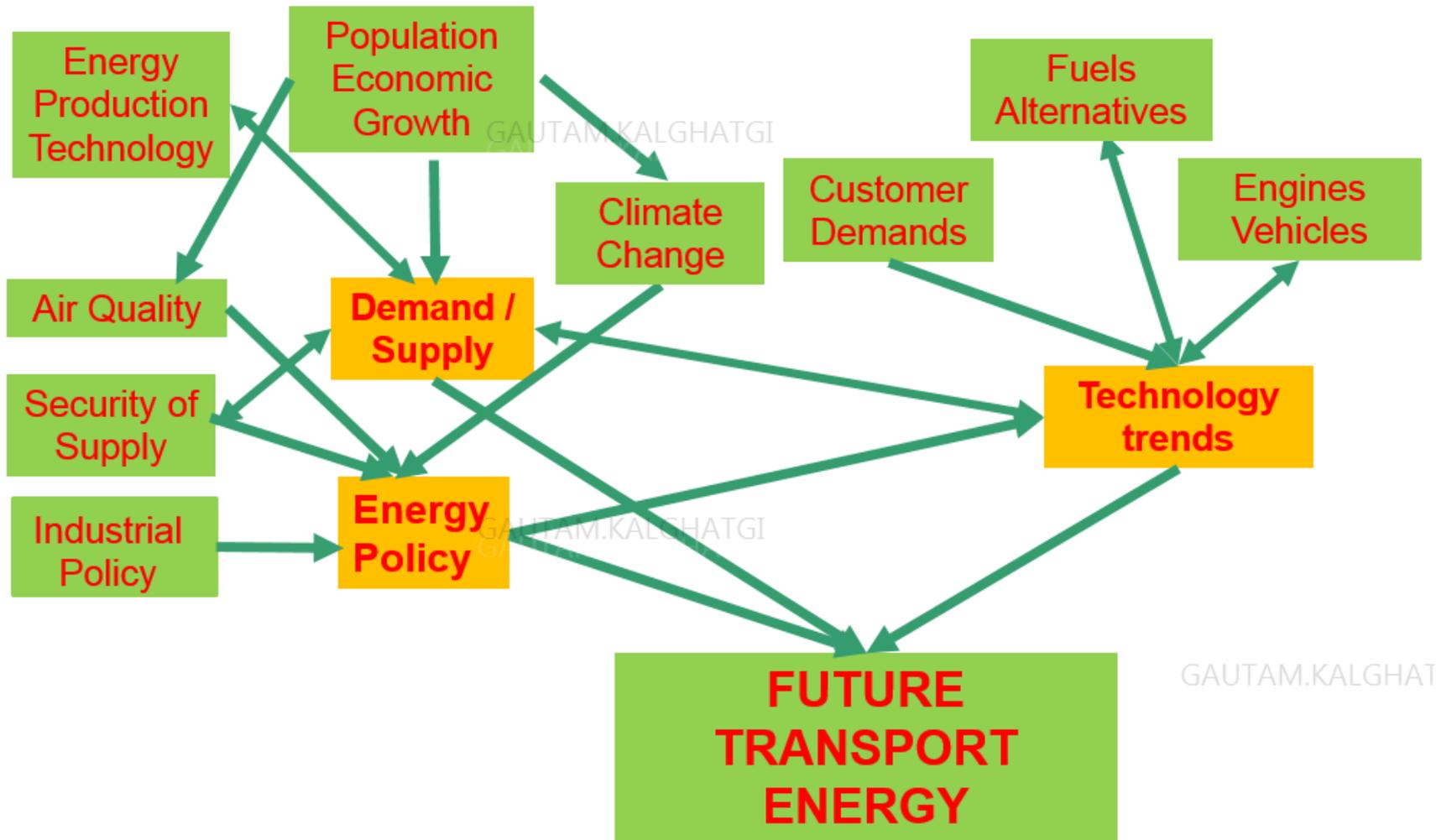
- 95% of transport energy from petroleum
- 60% of petroleum goes to transport fuels

## Introduction - II

Demand growth greater in commercial transport compared to LDVs

- Greater scope for efficiency improvements in LDVs - on average, in the future, lighter and smaller, cover less distance, hybridization
- Increase in demand for diesel & jet fuel rather than gasoline
  - Will require large investments in refineries
  - Greater availability of low octane gasoline components
- Even by 2040, transport will be dominated by combustion engines  
85%- 90% of transport energy will come from oil (World Energy Council, U.S. EIA)
- Imperative to improve such engines to improve the sustainability of transport

# Future Transport Energy - Many Drivers for Change



# Electrification of Transport

# Electric Vehicles - Different Degrees of Electrification

- Hybrid Electric Vehicles, HEVs (Toyota Prius) - Small battery. **All** their power coming from ICE but makes the ICE more efficient
- Plug-in HEVs, PHEVs (GM Volt) will have a larger battery but also a ICE- **some to most** of the energy from the ICE
- **Only BEVs do not have an ICE and all** their energy comes from the electricity grid. Large battery

**Electrification of LDVs will increase very significantly in the future - in the form of HEVs and maybe PHEVs but unlikely to be BEVs**

# Outlook for Electrification

- Global sales of plug-in EV (BEV +PHEV) rapidly increasing ~ 2 M in 2018 (less than 2.5%). Around 55% BEVs  
By end of 2018, global stock was, 5 M, 0.4 % of total passenger cars (<http://insideevs.com/>), ~3 M BEVs
- In 2040, LDV numbers expected to be 1.7-1.9 billion
- If ICEs are to be eliminated from LDVs by 2040, their number needs to increase by a factor of over 600, battery capacity by an even larger factor. But this still addresses only 45% of transport energy demand

Such a massive increase in BEVs will have unsustainable environmental and economic impacts.

# Greenhouse gas (GHG) and other pollutants

- GHG impact depends on how electricity used is generated.
- Battery production could generate up to 200 kg/kWh of CO<sub>2</sub>. In many parts of the world, certainly India and most of China BEVs will cause more (50% more in China) GHG than ICEV production.

India has reiterated that 75% of its electricity will come from coal for decades to come.

- PM<sub>2.5</sub>, NO<sub>x</sub> and SO<sub>2</sub> also will be worse if coal is a source of power.
- Human Toxicity Potential (HTP) - With ICEs, associated with NO<sub>x</sub>, particulates and other pollutants (e.g. “40,000 extra deaths because of diesel vehicles”). With BEVs, HTP is associated with mining of metals, particularly cobalt, and 3-5 times worse.

**BUT REPLACING ALL LDVs BY BEVS REQUIRES ~1000 TIMES INCREASE IN BATTERY CAPACITY**

# Full electrification not relevant to most commercial transport

- 36 tonne 500 mile range lorry - ~ 1000 kWh battery, 6.4 tons weight, cost over \$180,000. Charging time around 12 hours.
- A320 Neo carries 266 MWh of fuel energy. A battery pack carrying the same energy would weigh 1640 tons - 19 times the max take off weight. At 1 MW, would require 11 days to charge.
- Container ship Benjamin Franklin carries 4.5 million gallons of fuel, 170 million kWh. The battery pack would weigh over a million tons - 5.8 times the dead weight tonnage.

## Moore's Law for batteries?

- Not applicable. Electrons in a microprocessor do not take up space but ions in a battery do. Only new battery chemistry will bring major changes
- Gains in performance and reduction in cost typically 1.5-3% per year outside the microchip world ( Smil, <https://spectrum.ieee.org/energy/renewables/moores-curse> )

## Autonomous cars accelerate spread of BEVs? No!

- Level 5 autonomy requires 1.5 -3.75 kW of extra power + 1- 5 kW for heating and cooling
- A car on call for 24 hours with a 50 kWh battery cannot not go anywhere!

# Economic and Other Implications of Forced Electrification of LDVs

- cost/availability of new infrastructure such as charging points - <https://www.wsj.com/articles/the-problem-with-electric-cars-not-enough-chargers-1502017202> , £ 30-80 billion estimated for the UK - <http://uk.reuters.com/article/us-britain-power-autos-analysis/britain-faces-huge-costs-to-avoid-power-shortages-with-electric-car-plan-idUKKCN1BC3VU>
- Incentives to persuade motorists to buy them
- lost government revenue from fuel tax (£ 35 billion a year for the UK),
- cost/availability of extra electricity needed. Up to 8 GW (three nuclear power stations) needed in the UK if BEVs increase to 9 million (30% of total) by 2030 and they all wanted to charge at the same time <http://fes.nationalgrid.com/media/1281/forecourt-thoughts-v12.pdf>
- Eventually, the problem of recycling the batteries <http://www.sciencedirect.com/science/article/pii/S2214993714000037> and Olivetti et al. 2017, Joule 1:229-243
- Availability of cobalt and other materials - prices are increasing
- Ethical issues associated with mining of metals - <https://www.amnesty.org/en/latest/news/2017/09/the-dark-side-of-electric-cars-exploitative-labor-practices/>

Alternatives to Petroleum Based Liquid Fuels  
(electrification, biofuels, natural gas, LPG,  
DME, methanol, hydrogen..) not expected to  
take much more than 10% -20% share of  
transport energy by 2040

- Start from a very low base
- Significant barriers to unlimited growth
- Generally relevant to light-duty vehicles (LDVs)

- Even in 2040, ~90% of transport energy will come from petroleum-based fuels powering ICE
- Improvement of such systems is imperative to ensure sustainability of transport

# Ensuring the sustainability of transport

**Stage 1** - Conventional engines using known fuels e.g. gasoline, diesel, CNG, LNG, LPG, biofuels improve to reduce GHG and other pollutants. Better combustion, control and after-treatment coupled with partial electrification. Will also require some changes to fuels - e.g. gasoline anti-knock quality needs to be increased to enable higher efficiency in SI engines

**Stage 2** - **Developing new fuel/engine systems allows many of these constraints to be broken.** Unconventional engines e.g. Opposed Piston 2 stroke using 'new' fuels (not limited by existing specifications) might offer further flexibility. Such approaches will also help mitigate future supply/demand issues which are likely to arise under Stage 1.

**Stage 3** - Longer term. As overall energy system is decarbonized, and battery technology develops, increasing role for BEVs. Hydrogen and e-fuels

**Changes need to be assessed on a cradle-to-grave basis though some changes may be forced**

# Scope for improving ICE with existing fuels

Significant scope for improving efficiency of SI engines- Lean burn, downsizing/turbocharging, compression ignition, better control

- In the U.S., best-in-class efficiency is 16% better than average for cars of similar size and performance
- GDCI with market gasoline (Delphi) shows ~ 25% improvement
- Compared to 2015 fleet average, 30% improvement in the U.S. market is possible with combustion system improvements alone

Further improvements (up to 50%) possible with light-weight materials, vehicle down-sizing and partial electrification, demand reduction

Improved after-treatment - e.g. with particle filters, zero particles. With modern catalysts and intelligent control, exhaust could be cleaner than intake in many parts of the world

Some additional scope with “low-carbon” fuels if they make sense - proper life cycle assessment necessary

# Examples of fuel/engine system development

- **Gasoline Compression Ignition (GCI)** - run CI engines on low-octane gasoline rather than diesel fuel

**Overall GHG/Efficiency benefits** - ~ 25 - 30% wrt SI and ~5% wrt Diesel

**Engine** - Low injection pressures (< 500 bar). After treatment focus on HC/CO control rather than NOx and soot. **A simpler and cheaper diesel engine**

**Fuel**- Low Octane (70-85 RON, DCN < ~22), no stringent requirement on volatility. “Less processed” fuel.

**Demand/Supply** - Will help mitigate demand imbalance between diesel and gasoline that is otherwise expected

**Improve Sustainability of Refining**

- **Octane on Demand (OOD)** - Supply high octane fuel to SI engines only when needed - enables SI engines to run on low-octane gasoline but achieve high efficiency. Up to 5% GHG benefit. Requires two fuel systems on board.

Concepts proven in labs/demo vehicles. All stakeholders need to work together to bring such optimized fuel/engine systems to the market. Will become commercially attractive when price of low-octane gasoline drops

# Summary

- Global transport energy demand is large and increasing
- Different motivations for change in different places
- Alternatives start from a very low base, are costly/inconvenient and cannot grow without constraint
- Even by 2040, most (~ 90%) of transport energy will come from petroleum powering ICEs
- Alternatives need to be assessed on a life cycle basis
- GHG and other impacts of transport can be reduced only by improving ICEs
- More diesel and jet fuel needed compared to gasoline AND increase in octane of gasoline pool
- Great challenge to the refining industry - huge investments (100s of billions of \$) AND surplus of “low-octane gasoline”
- Great scope for developing highly efficient engines running on such fuels
- Gasoline Compression Ignition (GCI) or Octane on Demand (OOD) engines offer such a prospect
- All stakeholders need to work together to bring such optimized fuel/engine systems to the market rather than only developing engines for existing market fuels
- Meanwhile there will be increasing electrification - mostly hybridization which will help ICE improve

THANK YOU FOR YOUR  
ATTENTION