The outlook for transport energy and the scope for combustion research

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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_2, methane and nitrous oxide) emissions, 20% of total energy use, 23% of CO_2 emissions
- Currently over 1.2 billion light duty vehicles (LDVs) and over 350 million commercial vehicles
- 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.
- LDVs account for ~44% of global transport energy demand

Petroleum and transport closely linked

- Transport is essentially driven by liquid fuels – high energy density, ease of transport and storage, extensive infrastructure
- 95% of transport energy from petroleum
- 60% of petroleum goes to transport fuels

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

- In non-OECD countries

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

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 ~ 1.2 M in 2017 (less than 1.5%). Around 55% BEVs

By Aug 2018, global stock was, 4 M, 0.3 % of total passenger cars (http://insideevs.com/), ~2 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 nearly 1000. But this still addresses only 20% 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 generates up to 200 kg/kWh of CO_2. 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.
- Electricity on demand is usually fossil fuel electricity (no solar at night)
- PM2.5, NOx and SO_2 also will be worse if coal is a source of power.
- Human Toxicity Potential (HTP) - With ICEs, associated with NOx, 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 THEIR NUMBER

Full electrification not relevant to most commercial transport

- Tesla S – 85 kWh battery pack weighing 544 kg. Cost $180/ kWh. With the 120 kW Tesla supercharger charging time 60-75 minutes
- 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 – 21 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

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

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

Research Requirements

Experiments and modeling to understand complex combustion systems and new problems (e.g. preignition and superknock)

- Combustion/flow interactions
- Fuel injection and mixture formation
- Combustion chemistry and Chemical kinetics
- Pollutant formation
- Life cycle analysis to get honest assessment of competing solutions
- After-treatment systems – e.g. low-temperature catalysts
- Engine control systems

THANK YOU FOR YOUR ATTENTION