AWBriefing

Discussion Debate Networking

Decarbonising The Automotive Industry

Lotus Engineering

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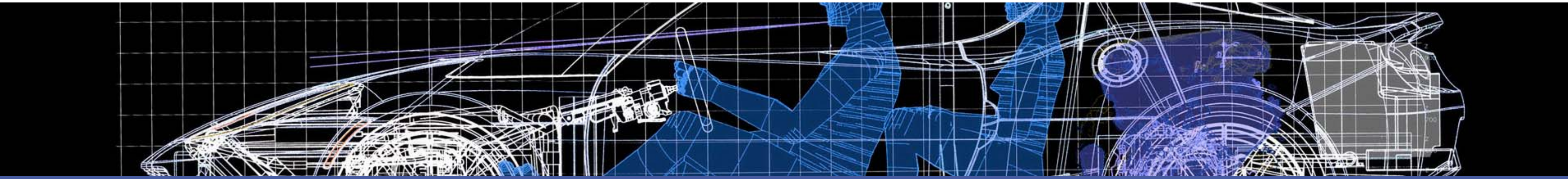

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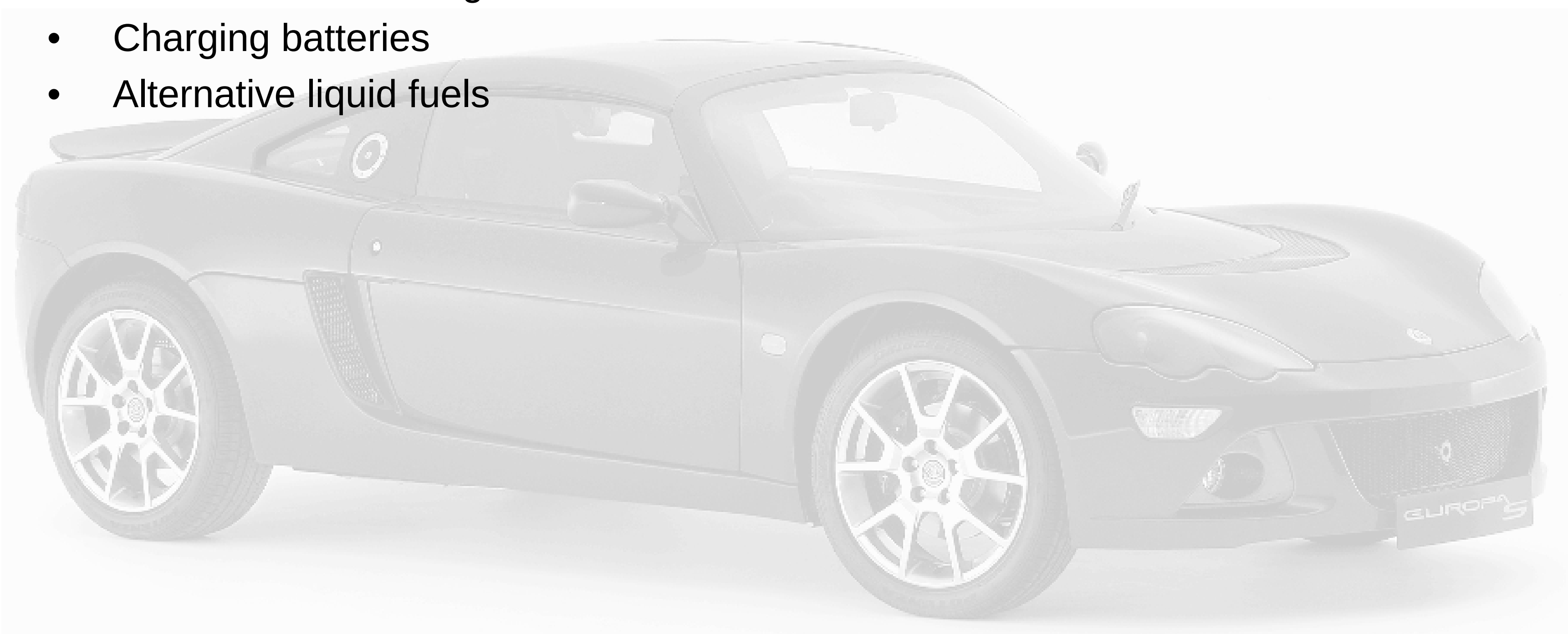
Automotive Industry Challenges

- Lower carbon footprint
- Less reliance on fossil fuels
- Affordable technologies for the consumer

Discussion Points

- Technology Overview
- Technical Challenges
- Manufacturing Challenges
- Commercial Challenges
- Charging batteries
- Alternative liquid fuels



Technology Overview

Most technologies are relevant – but to differing applications

- Pure EV & Hybrid types and appropriate market applications
  - Electric (light and medium passenger vehicles; motorsport)
  - Electric (heavy passenger & goods vehicles; motorsport)
  - Kinetic (passenger vehicles; motorsport)
  - Hydraulic (heavy passenger & goods vehicles)
  - Pneumatic (passenger vehicles…..)

- Fuel Cells
  - Hydrogen economy

Fuel storage & infrastructure issues

- Combustion Engine design
  - Alternative cycles & fuels (Atkinson; Miller; E85 etc)
  - VVT; CDA; GDI etc
  - Range extenders (optimised for single speed & load)

'Traditional' mechanical design

Technologies – Near Term

- Electric
  - Energy storage
    - Battery (NiMH & lithium cell chemistries)
    - Supercapacitors
  - Electric motors
    - Specific power output
    - Idle stop
  - Power electronics
    - Miniaturisation (integration with motor)
  - Charging
    - Energy provision for ‘fast charge’
    - Equipment & Infrastructure
    - Design for battery replacement
  - Whole Vehicle Energy Management
    - ‘SmartNav’

Power (density) to weight ratio

Energy supply

Efficiency

Near Term, continued…

- Kinetic
  - Flywheel devices (KERS); flywheel ‘battery’
  - Driven by FIA regulation changes for 2009
  - Good specific energy storage
- Hydraulic
  - Energy storage
    - Accumulator (pressurised nitrogen; 5000 – 7000 psi)
  - Hydraulic pumps & motors
    - Specific power output
  - Valves & blocks

Power to weight ratio

‘Traditional’ mechanical design

Lower cost compared with electric hybrid

Although possibly more efficient than electric hybrid, there is no provision for ‘off-line’ charging

Electric Hybrid Vehicles

- Micro
  - Stop / start systems
- Mild
  - Low electrical power
  - 10kW to 15kW
- Full
  - Higher power (30kW+)
  - EV only mode

~5% less CO_2

~15% less CO_2

~20% less CO_2

- Parallel
  - Engine connected to the wheels through transmission and driveshafts

- Series Hybrid
  - No mechanical link between engine and roadwheels

- Mode switching
  - Can operate series or parallel

Technical Challenges

- Energy storage
  - Battery - Future cell chemistries
  - Supercapacitors (More efficient packages)
  - Higher voltages (kV)

- Electric motors / power electronics
  - Higher voltages (kV)
  - Aluminium windings
  - Miniaturising components

- Superconductor materials
  - Driving system efficiencies up

- Fuel Cells
  - Hydrogen or Solid Oxide
  - Higher power outputs

- Communication
  - Car-to-car
  - Autonomy

- Regenerative Braking
  - More regen = higher motor power

- High power distribution
  - Cables
  - Components

Manufacturing Challenges

- Motors
  - Weight
  - Strong magnetic fields
- Batteries
  - Storage & Stability of raw materials
  - Weight
  - Pack size
  - Cell layout; mounting; cooling
  - Internal cabling
  - High Voltage (shock risk)

Battery pack handling

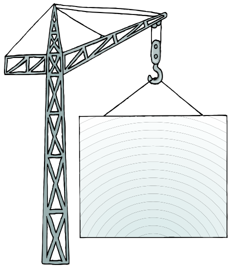
- **Transportation of dangerous goods including:**
  - ST/SG/AC.10.11/Rev 4 Part III subsection 38.3 (EU)

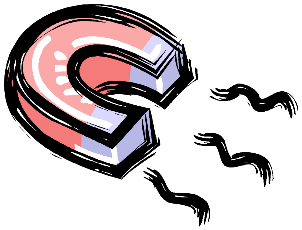
  - Shipping of batteries, must pass:
    - T1 Altitude Simulation
    - T2 Thermal
    - T3 Vibration
    - T4 Shock
    - T5 External Short Circuit
    - T6 Impact
    - T7 Overcharge
    - T8 Forced Discharge

Regulates transportation of lithium based cells and batteries

Vehicle Assembly

- Weight & size of battery pack to manoeuvre into vehicle
- Magnetic field of motors affecting
  - Clothing
  - Jewellery
  - CRT's
  - Tools
  - Attraction of ferrous dirt / debris
  - Magnetic Shielding?
- Risks associated with High Voltage
  - Arcing of high voltage
  - DC presents risk of muscle clamping on electrocution
  - Charged Capacitor shock





Commercial / Legislation Challenges

Cost of battery pack

100kWh @ $300/kWh

$30,000

Cost of motors

125kW

$20,000

Market immaturity

No economies of scale

Deletion of friction brakes with the introduction of 'pure' regen braking

‘C’ Rating and charging

- If the EV pack is **100kWh** capacity
- And the pack is charged in **10 minutes**

Such cells do exist

The energy required is 600kW

- A domestic 220V, 13A socket will provide **2.8kW**

Clearly, fast charging will require specialist equipment

Charging – the future?

- Charging Infrastructure
  - Domestic charging times still a limiting factor
  - Design for easy replacable batteries
    - Swapped out at commercial charging stations
  - Cell manufacturers now claiming 50C current rates
    - 100’s of kW to be provided by charging apparatus
  - Design of charging stations
    - JVs with Energy suppliers / utilities

Energy Capacities

- Relative capacities of energy storage systems are different

C Segment EV	VW Golf 1.6
28kWh battery	2.1 gallons fuel
101MJ	337MJ
~ 210kg	~ 6.7kg
90 miles range	90 miles range

- This highlights 2 points:

1. The relatively high energy density of liquid fuels compared to electrical storage

2. The low efficiency in converting liquid fuel into kinetic energy in an IC engine

Alcohols as the Alternative Fuel

- Alcohols are liquid fuels with relatively high on-board energy density
  - Using simple and light weight gasoline-compatible fuel systems
- They can be distributed via a modified existing infrastructure
- Blending alcohols with gasoline is simple
  - No engine modifications are necessary up to 10% by volume
- Engine modifications for higher concentrations are minimal
- Alcohols have high octane indices and this enables better combustion efficiency
  - High knock resistance is ideal for downsized engines
- In 'biofuel' form they offer significant well-to-wheel CO_2 benefits
  - But presently there is insufficient cultivated land area
  - "Second generation" biofuels will improve this situation
- The cost of 'flex-fuel' capability is trivial
  - All new spark ignition vehicles could be made flex-fuel compatible at minimal on-cost

Methanol as an Alternative / Renewable Fuel (1)

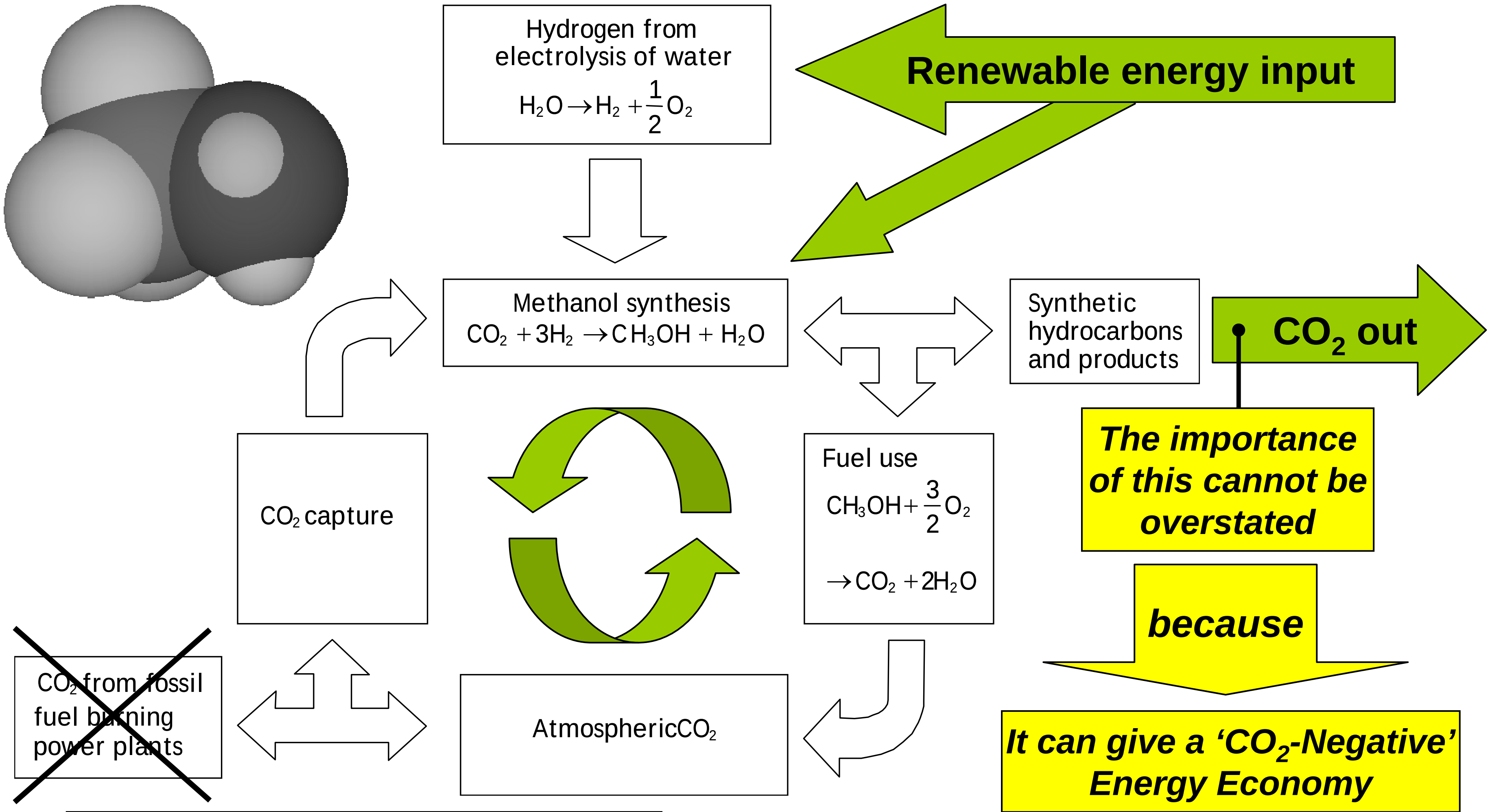
- Alcohols can be synthesized from biomass, gaseous hydrocarbons or from hydrogen and carbon dioxide
  - They are alternatives to hydrogen to minimise climatic impact
  - Excellent potential candidates for the long-term energy economy
- Professor George Olah and co-workers at USC have proposed the use of methanol as a basis for the future global energy economy
  - Because it is a liquid energy carrier and it will not impact food production
  - Methanol has been produced from CO_2 and H_2 for many years – the limiting factor on production is the availability of feedstocks
- Production of the necessary H_2 can be via electrolysis of water
  - Additionally, the 'Carnol' process generates H_2 from thermal decomposition of methane giving H_2 and solid carbon
  - The solid carbon residue is then easy to sequestrate
- In the longer term, CO_2 can be obtained directly from industrial flues or cement production
  - 'One more pass' before atmospheric release

Methanol as an Alternative / Renewable Fuel (2)

- In the long-term, to deal with small and dispersed CO_2 emitters, a very feasible approach is to **extract it from the atmosphere**
  - Extraction facilities could be located anywhere
  - Obviates the energy security issue
- Atmospheric CO_2 can be extracted by large-scale absorbers
- Work on KOH-based absorbers shows that the resulting K_2CO_3 can be electrolysed to give H_2 and CO_2 with small energy inputs
- Methanol is easily converted into ethylene and propylene, to form the basis of a synthetic hydrocarbon industry
  - This output provides capacity to input fossil fuels into the cycle
- Ultimately the cycle is dependent on the long-term development of efficient renewable / nuclear base load electricity generation

Which would have to be done for renewable hydrogen fuel anyway

Proposed Methanol Cycle



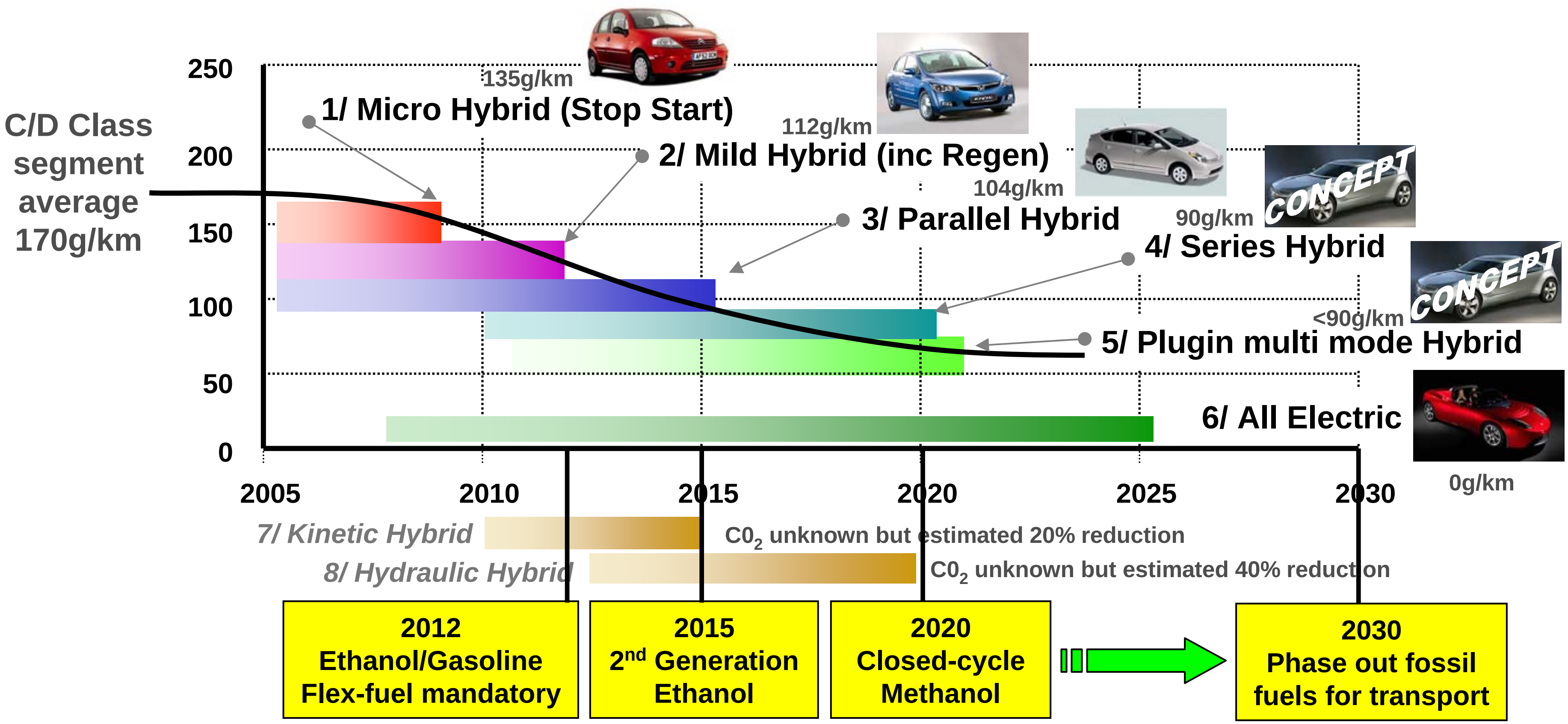
Source: Olah *et al.*, "*The Methanol Economy*"

How we could reach a CO_2-Negative Scenario

- Lotus believes that in 2012 legislation requiring all gasoline vehicles to be gasoline/ethanol flex-fuel should be enacted
  - Gives a significant market incentive to renewable fuels suppliers
- 2nd Generation Bioethanol can be developed to meet demand
  - Industrial production 2015?
- Simultaneously research methanol synthesis from atmospheric CO_2
  - Industrial production by 2020?
  - Together – ***A Synthetic Alcohol Energy Economy***
- Widespread methanol usage would then be supported primarily by software changes in the existing vehicle fleet
- Synthesize diesel from methanol using Fischer-Tropsch process
- *Begin to phase out fossil-based gasoline and diesel from 2030*

2012	2015	2020	2030
Ethanol/Gasoline Flex-fuel mandatory	**2nd Generation Ethanol available**	**Closed-cycle Methanol production**	**Phase out fossil fuels for transport**

Low CO_2 Vehicle Development Conclusion



- Downsizing, Biofuels and Hybrid systems are complimentary and enable evolutionary steps in technologies towards a clean renewable transport system (chiefly electric transport economy)
  - High energy liquid fuels will always be needed for remote travel

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