Fuel Cells :Holy Grail or Illusion?

Does Carnot's Cycle

have a

Long Road Ahead?

Engine Expo 6-8 May 2008, Stuttgart
Open Technology Forum

Fuel Cells

The Perfect Automotive Power Plant?

or

The Emperor's New Clothes?

- **Beethoven's 9th Symphony first performed**
- **Carnot's Paper Published**

' Refléxions sur la Puisance Motrice du Feu et
Sur les machines propres a développer cette puisance '

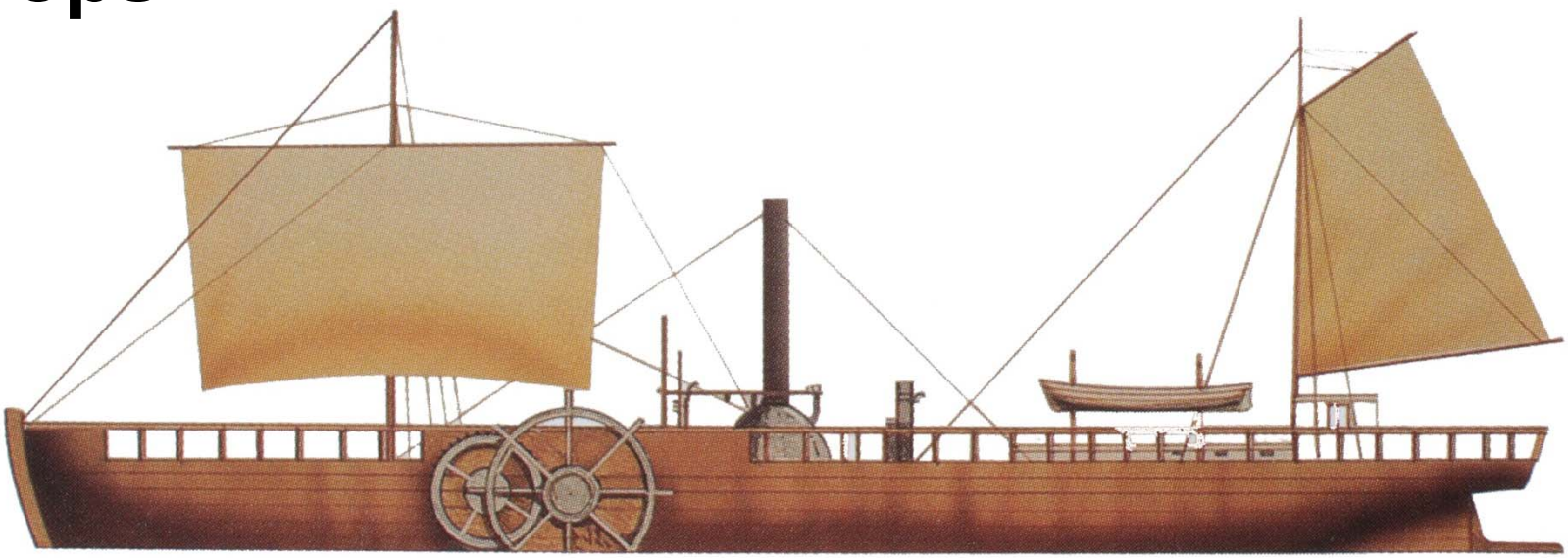
Sadi Carnot: Aged 17 in 1813

Carnot's Insight

- **The 'Thermal Efficiency' of a perfect heat engine can be defined**
- **A basic engine cannot extract 100% of the thermal energy in fuel**
- **Note: today's automotive engines have around 35% best thermal efficiency**

First Passenger Steam Ship

- **Clermont steamer 1807**
- **140 passenger capacity**
- **Outperforming land coaches and river sloops**



A Fuel Cell

- **Hydrogen plus Oxygen**
- **Catalyst**
- **Water plus electrical power**

Support for Fuel Cell R&D

- **World wide interest for all types**
- **Major focus for government establishments**
- **Major focus for automotive industries**
- **Annual expenditure: $100's millions**

Fuel Cell Issues

- **Complex chemistry in the cell and catalyst; currently uses empirical design rules**
- **Too large; not robust; too expensive**
- **Product acceptance tests for real world application not yet validated**

Fuel Cells v's ICE's : The Big Issue

- **'Thermal efficiency*' of an automotive fuel cell may be limited to 60% peak.**

BUT, a fuel cell can maintain this level of efficiency at low loads.

- **An ICE has an efficiency of only up to ~40% peak.**

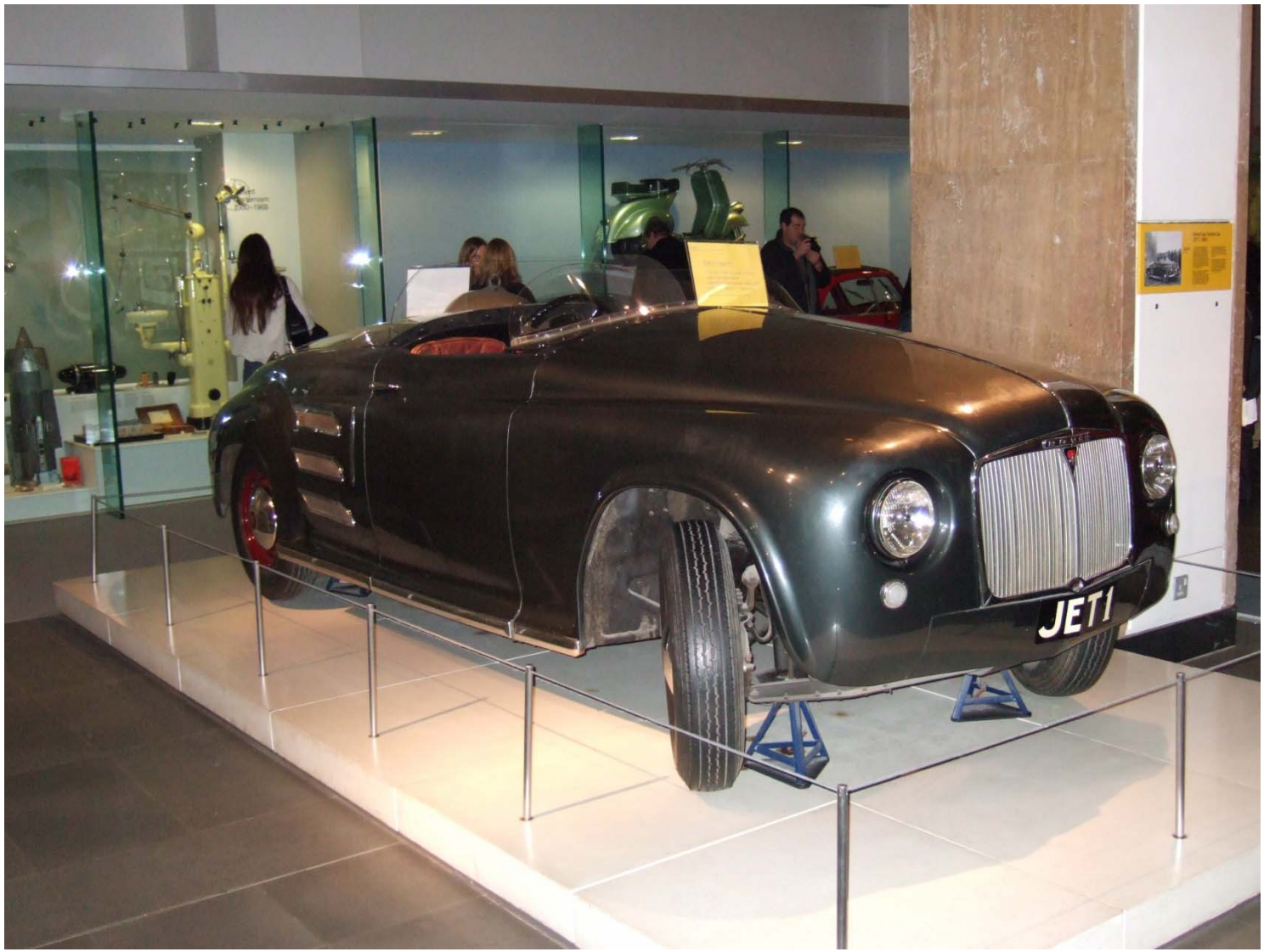
AND an ICE loses efficiency at low loads.

More precisely, electrical output compared to chemical energy in the input

Automotive Advanced Projects 1960's and 1970's

- **Gas Turbine vehicles produced as prototypes**
- **Stirling Engine projects**
- **Wankel engine gets attention at 'Big Three'**
- **Expenditure measured in $100's millions**

Rover Gas Turbine Car



Ford ‘Big Red’ GT Truck

The Empire Strikes Back: 1

- **Why the effort on alternative powerplants?**
  - **Fear that ICE's would be 'killed off' by emission regulations from Clean Air Act of 1967**

However!

- **Advanced emission controls have kept ICE's at front**

Will the Empire Strike Back Again?

- **Can the Internal Combustion Engine keep the Fuel Cell at bay in the future ?**

Already in the 'pipe-line'

- **Downsized and advanced boost schemes**
- **Combustion : 2nd Generation GDI, Dies-Otto, HCCI?**
- **Fuels : Sustainable bio-fuels and hydrogen**
- **Hybrid systems : 'plug-in' ICE and battery**

Not yet 'exploited'

- **Maximise use of fuel economy 'sweet spot'.....the IVT**
- **Braking energy recovery.....flywheels**

Hydrogen and ICE's

- **September 2006, Graz, Austria**
  - **MAN - accumulated 400,000km in city buses with Hydrogen ICE's**
  - **BMW - previously announced lease of V-12, 7 series cars. Bi-fuel H2 and gasoline**
  - **Ford - comprehensive account of hydrogen engine and vehicle for E-450 airport bus**

Hydrogen ICE vs. Fuel Cell

- **Installed Thermal Efficiency**
  - **By 2010 (Argonne)**
    - **Optimistic value for diesel 45%**
    - **Optimistic values for fuel cell 60%**
  - **BMW Chief Research Engineer**
    - **The H2 ICE could achieve.... 50%**
- **Note: a gain of 10-15% is not enough for large volume adoption of fuel cells.**

Greenhouse Gases

- **Hybrid diesel ~ 250 g/mile**
- **Hybrid H2 Fuel Cell ~ 280 g/mile**
- **Hybrid H2 ICE ~ 310 g/mile**

- **Note:**
  - **Diesel fuel is low sulpher**
  - **Bio-diesel - will reduce effective GHG's even lower**
  - **Hydrogen from natural gas WITHOUT CO^2 sequestration. Renewable / nuclear hydrogen ~ 50 g/mile.**

How IVT Works

1. The input disc(s)

Powered by the engine

2. The variator roller(s)

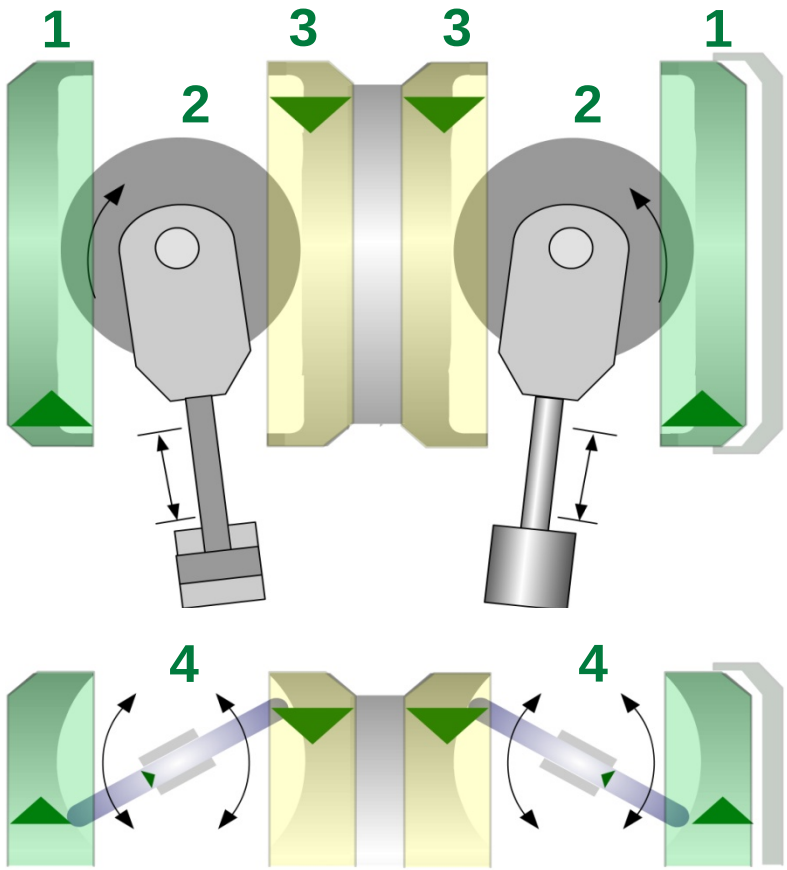
Transfer power and match Disc speeds…

3. The output disc(s)

Transmit power to the drive shaft

4. Ratio Change

Rollers “steer” like a castor to reflect the ratio change.

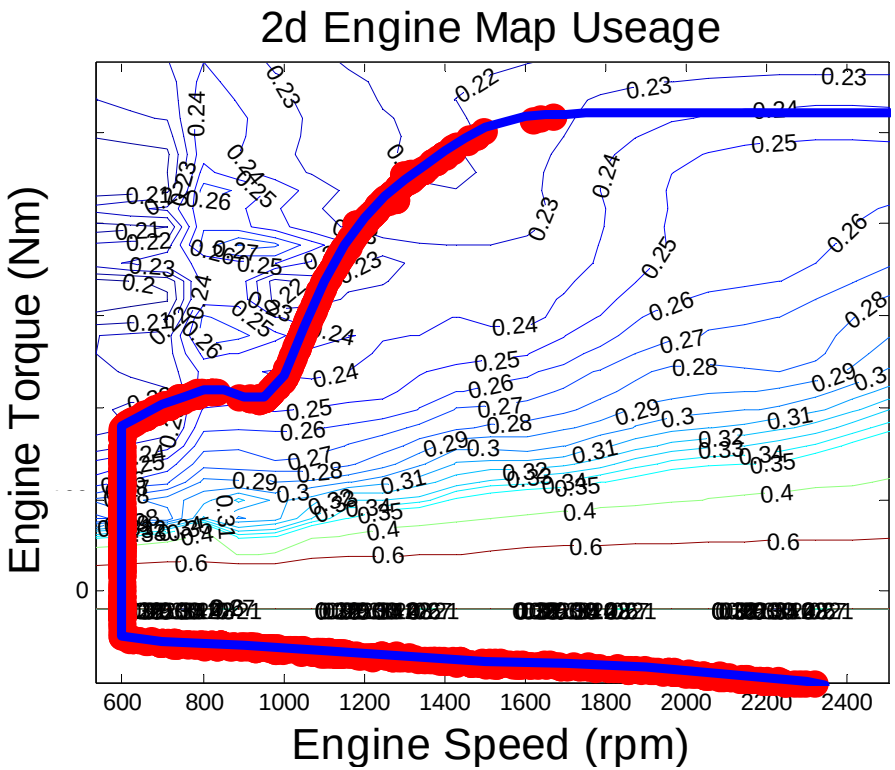


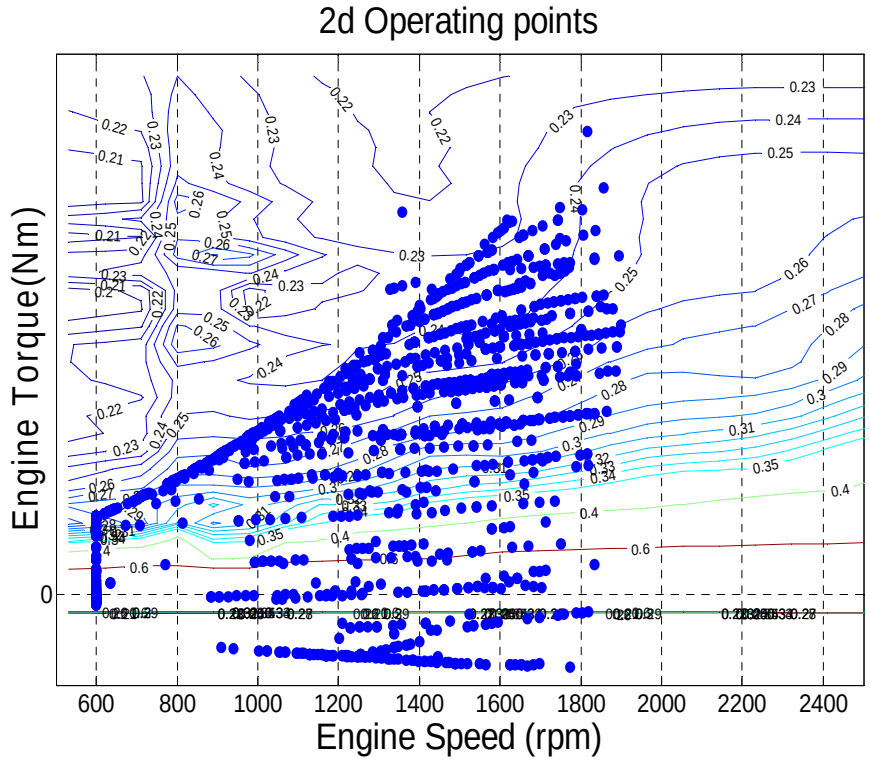
IVT – Fuel Economy in Bus Applications

- **Replacing a 5-speed automatic with an IVT**
  - **Measured 19% reduction in fuel use**
  - **Corresponding reduction in CO_2 emission**

- **IVT enables**
  - **Accurate control of engines**
  - **New engine technologies**
  - **Optimised drivelines**
  - **Novel hybrid strategies**

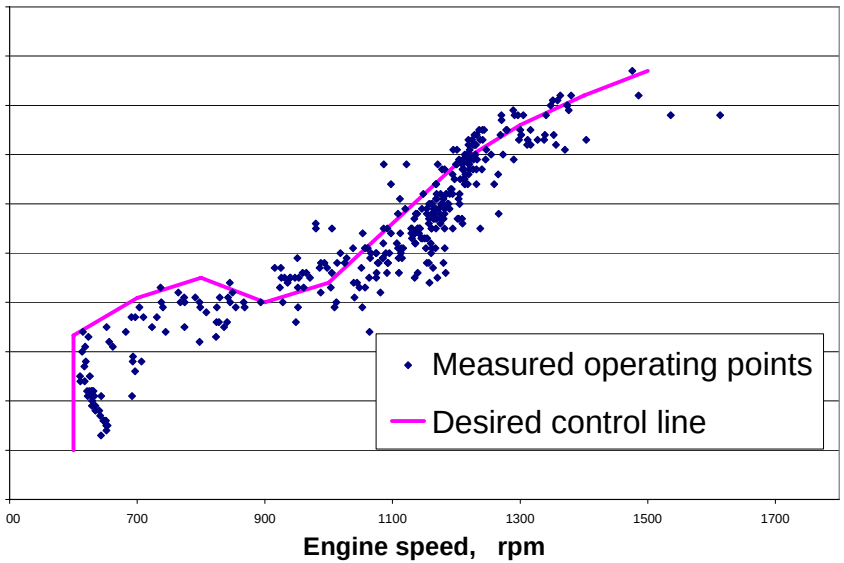
Engine Operating Points –Theoretical

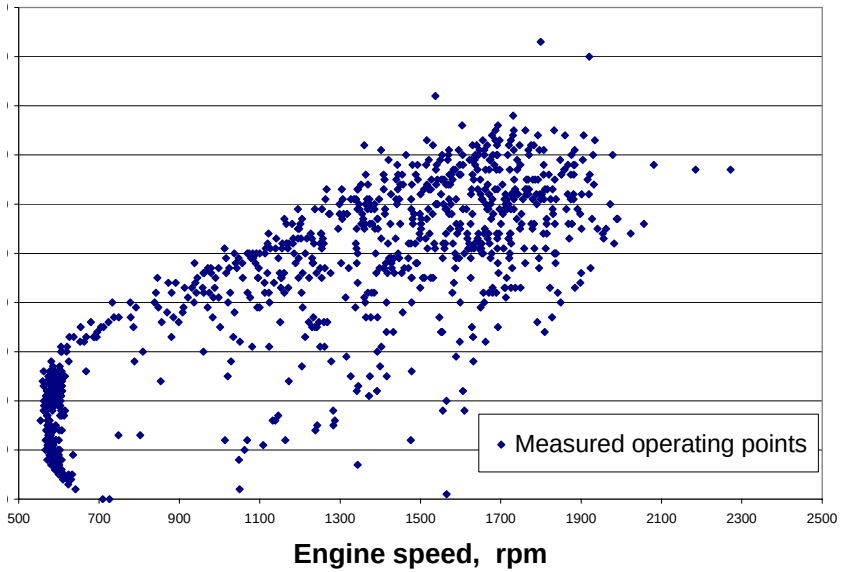




- IVT optimal control line
- 5 AT operating envelope

Engine Operating Points – Measured Millbrook London Transport City Route 153





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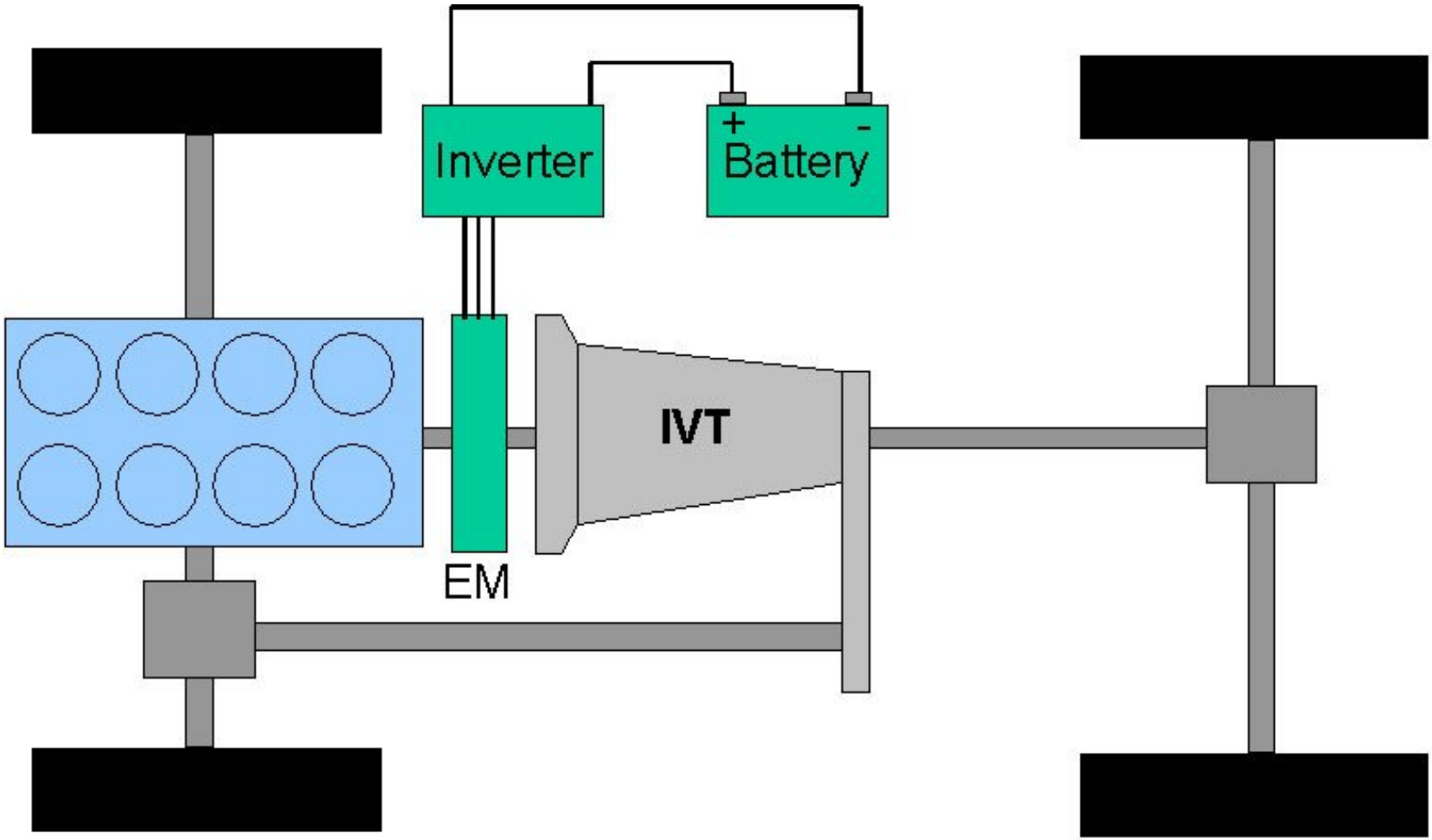
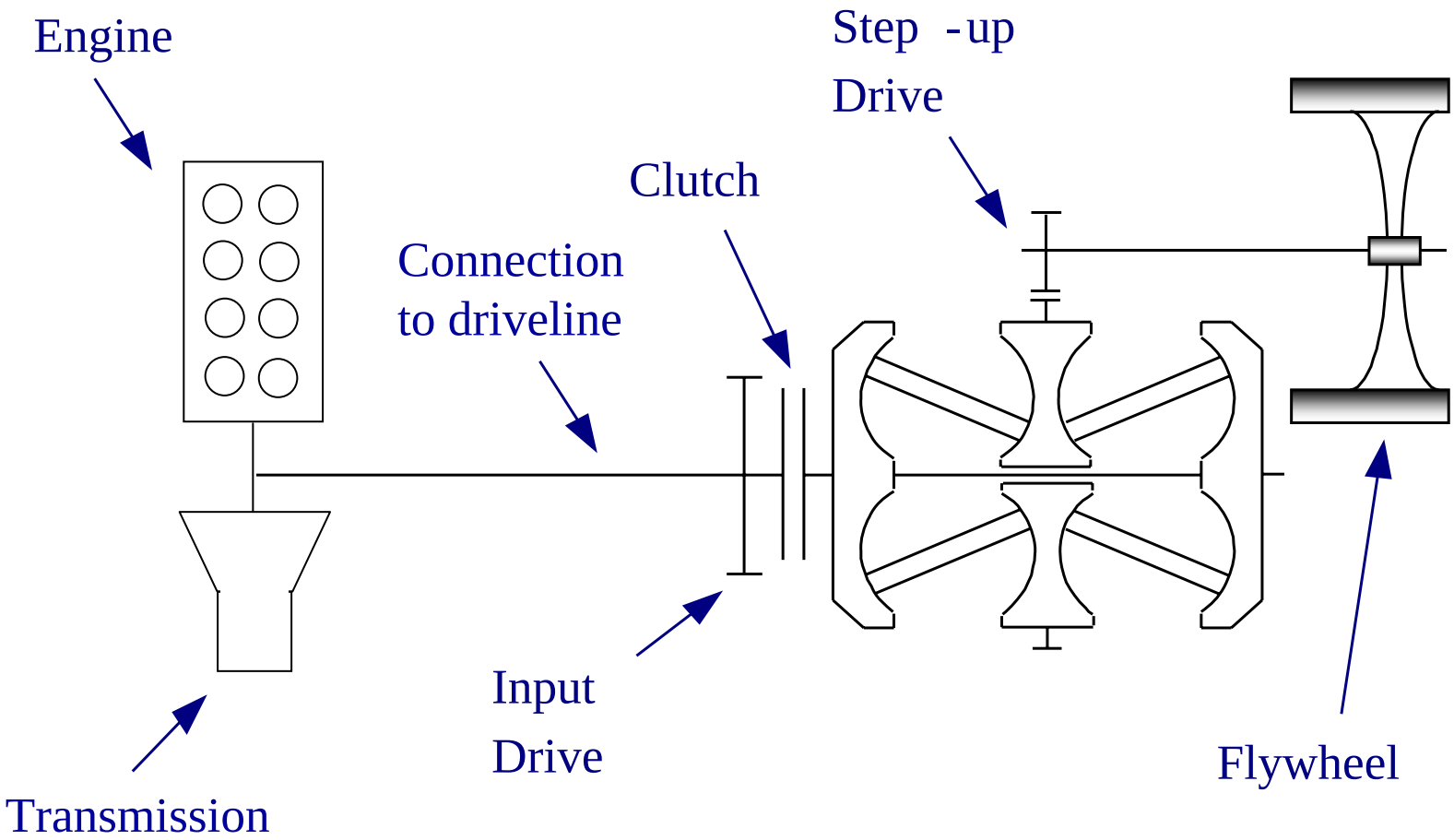
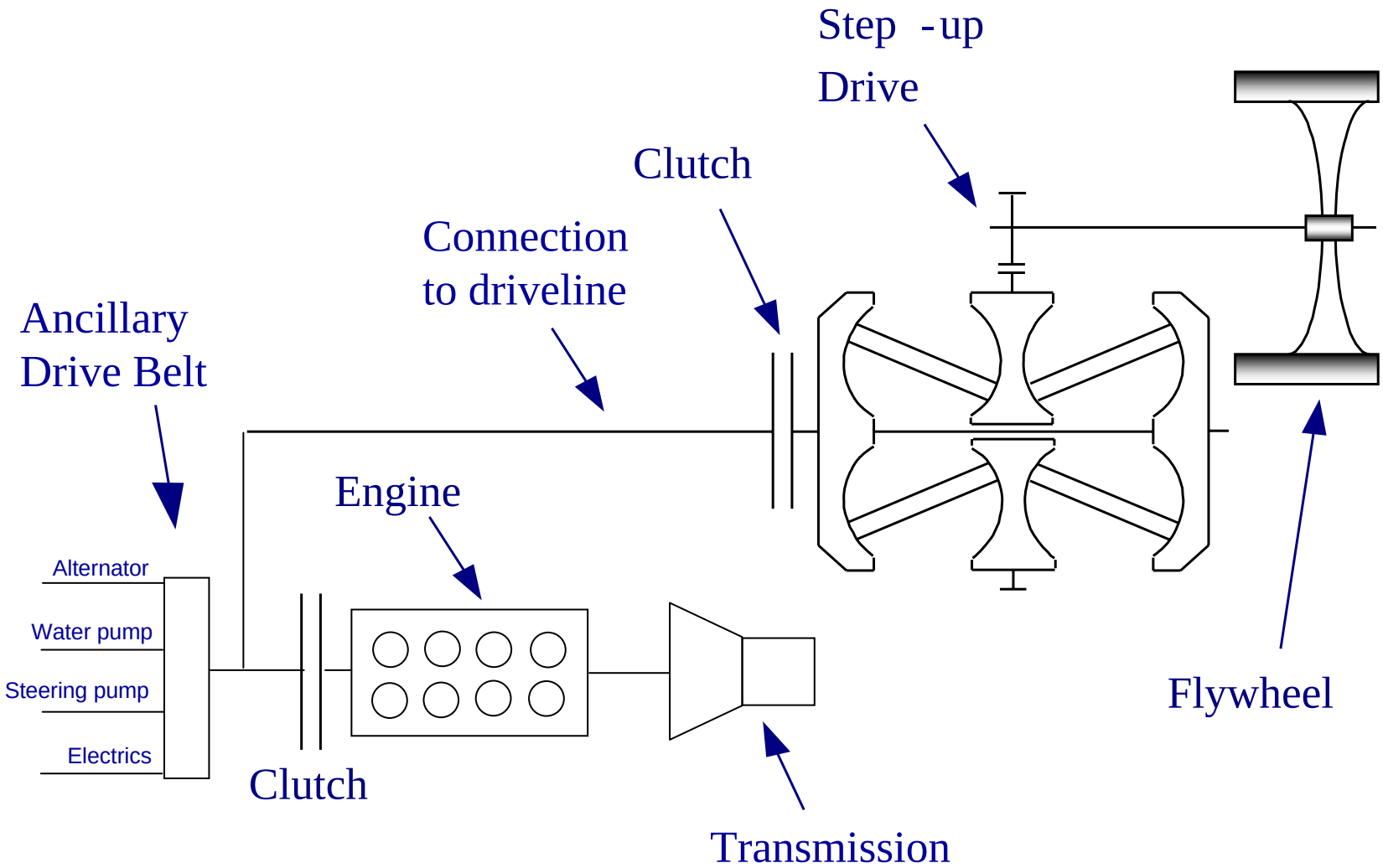
IVT in a Hybrid



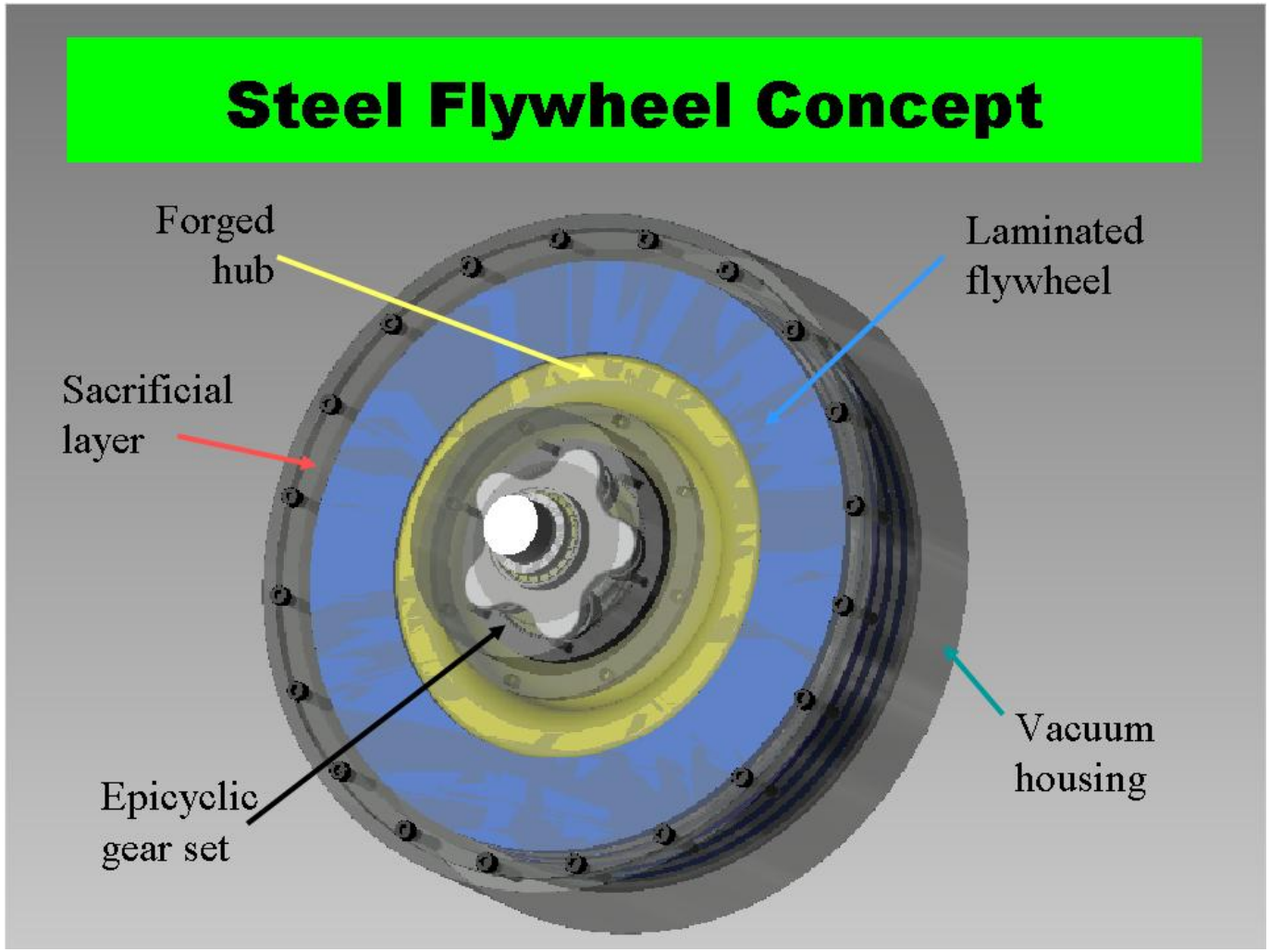
Mechanical Hybrid: KERS Configuration



KERS - Ancillary Drive Application



KESTREL Project



Fuel Cells: The Future

- **Not yet proven they can fulfil the aspirations of their protagonists in the long term**
- **The Internal Combustion Engine will fight back - burning hydrogen and bio-fuels**
- **Are Fuel Cells another example of:**

  " The Emperor's New Clothes " ?