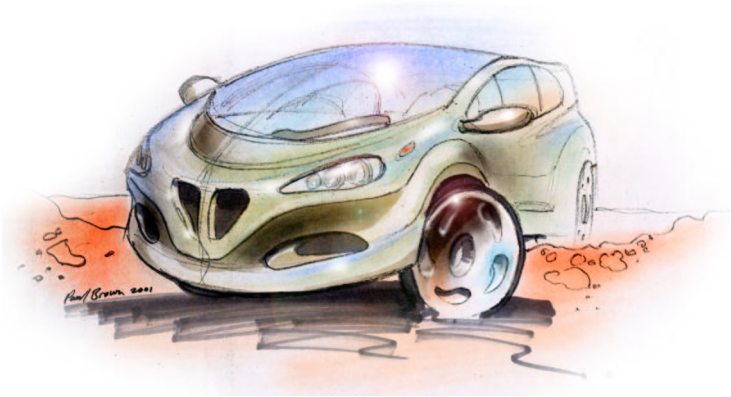

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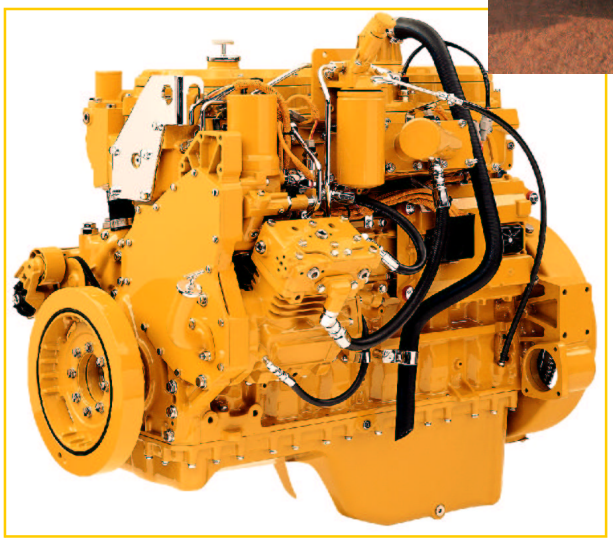

Controlling Propulsion Systems of the Future

IEE Cambridge Meeting, CARTRONICS
4th December 2003
Richard Stobart

Controlling Propulsion Systems of the Future

- Defining the future powertrain
- Identifying the constraints
- Control objectives and functions
- The need for supervisory control
- How fuel cell vehicles are controlled
- The implications for control systems hardware (or perhaps software?)

Defining future propulsion systems for v

- There is some consensus that the future is hybrid
- There is a strong interest in hydrogen as an energy medium – *but it is not a fuel*
- The fuel cell offers the promise of high efficiency and low emissions
- The diesel is likely to remain cost effective
- All future powertrains have two important features that will force control system choices

  Supervisory control

  Complexity

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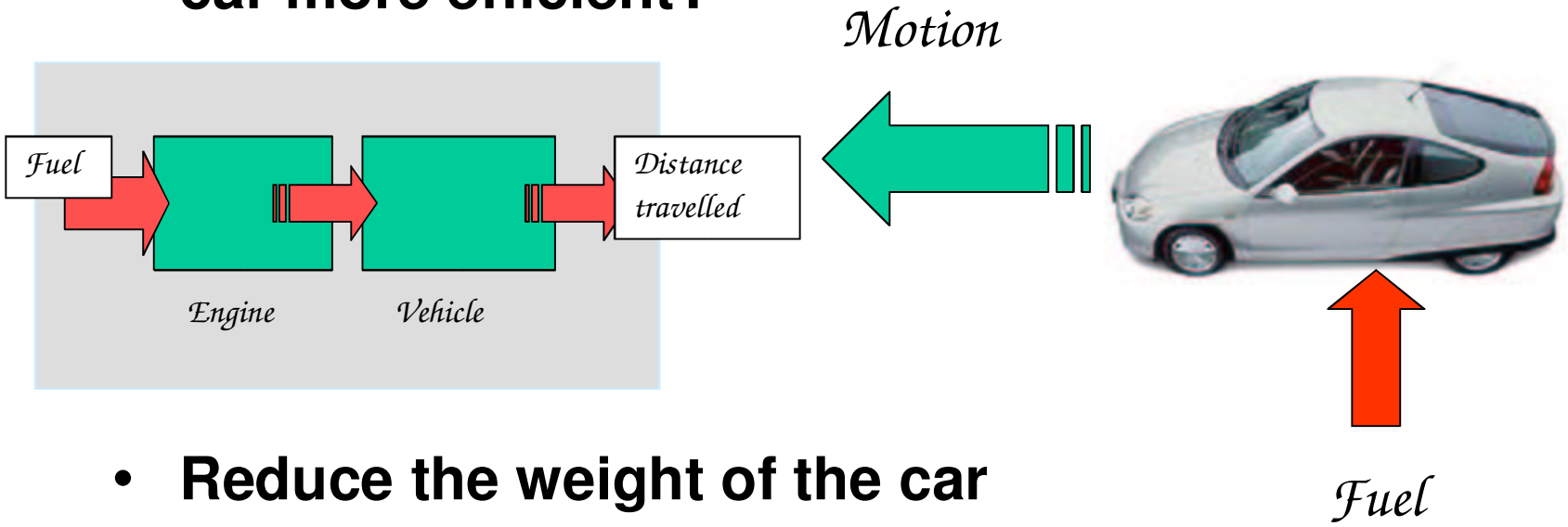
What different techniques can be used to make the car more efficient?



- **Reduce the weight of the car**
- **Choose a different type of engine**
- **Use less braking, or**
- **Simply drive less?**

But less weight = more dangerous car … or does it??

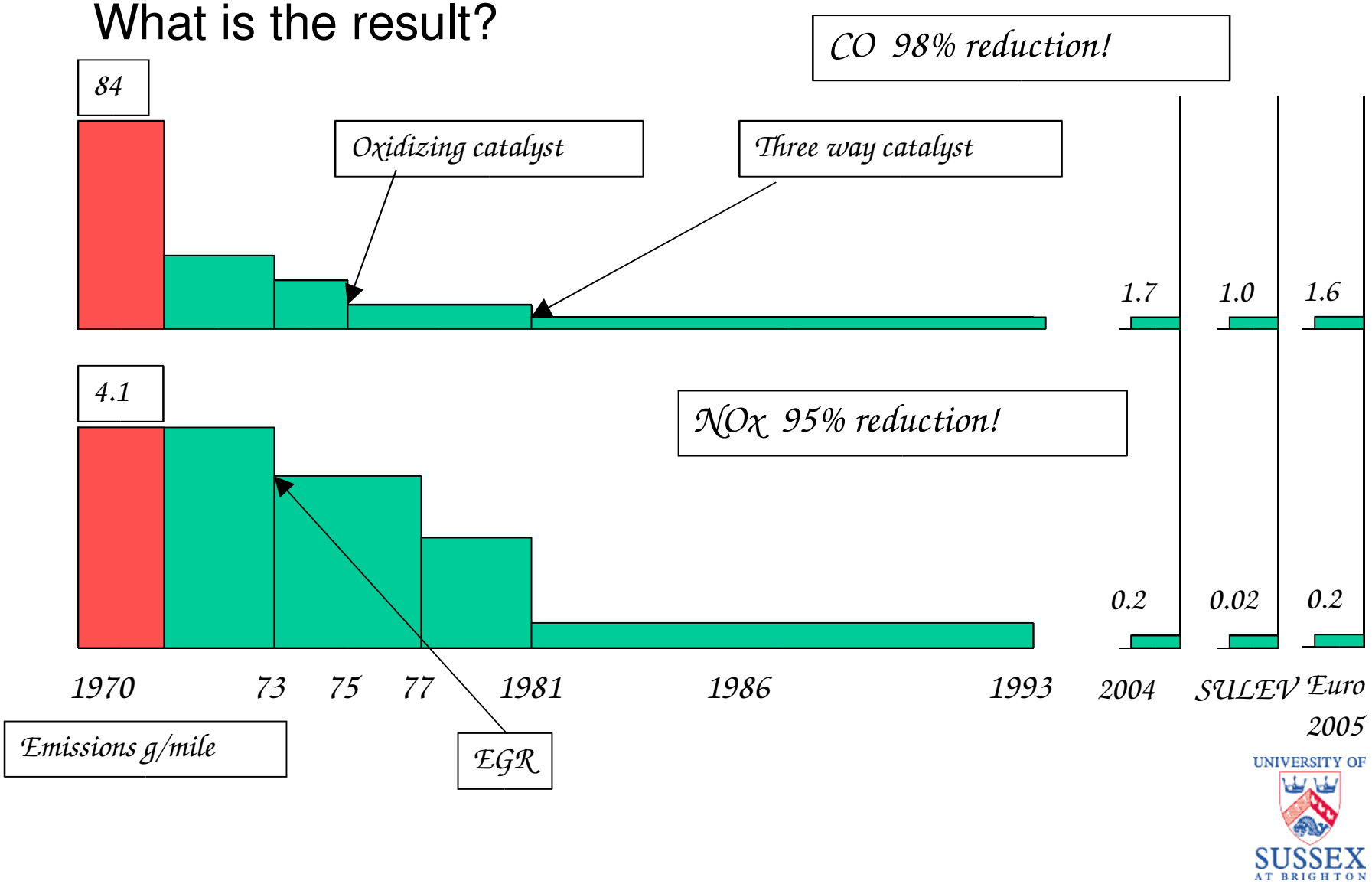
Work at BMW on Driver Assistance has demonstrated substantial efficiency improvements

- the on-board system uses knowledge of the road and traffic conditions, sensed and recorded
- the driver is informed through ‘active controls’
- potentially up to 30% of fuel consumption can be saved by avoiding or reducing braking

Carbon dioxide emissions are a system issue – not simply a vehicle design issue!

Refs: FISITA paper F98S205 “New Energy Savings Potential by Combining Telematics with Driveline Management”, www.bmw.de

What is the result?



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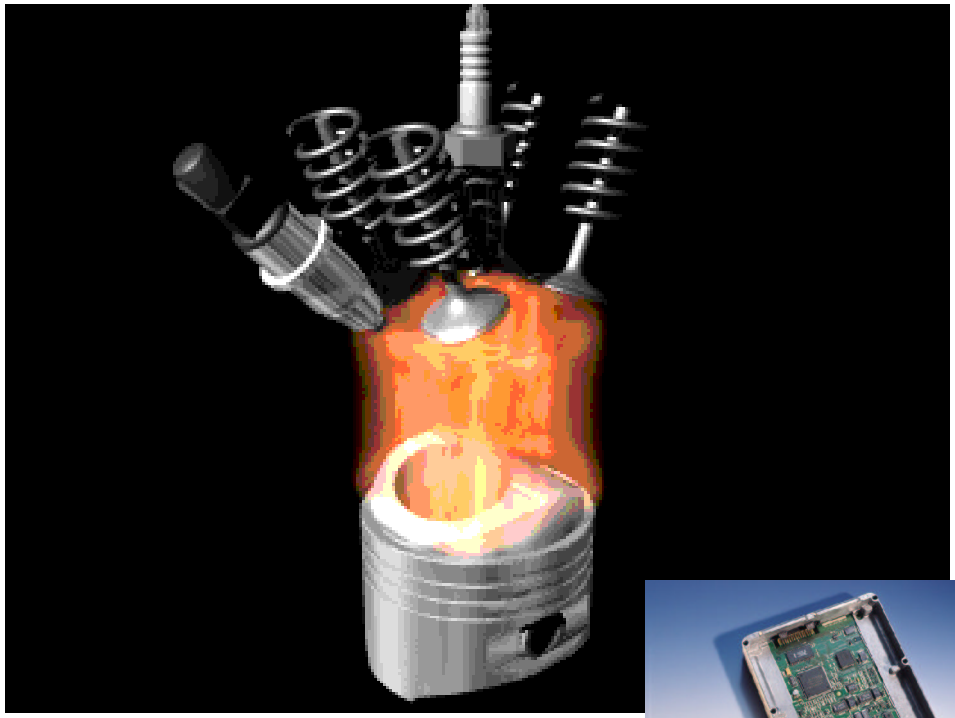
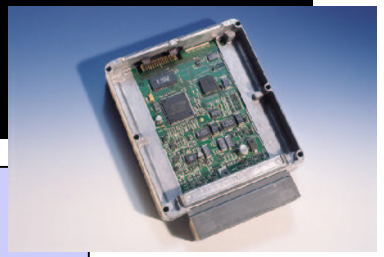
Novel combustion systems offer significant gains in efficiency

- *Stratified charge has a long history*
- *GDI is a modern development of this idea*
- *Auto-ignition leads to new possibilities*
- *HCCI is a possibility but needs control action*





What is the potential for fuel economy?

- *Probably 7-8% allowing for all future improvements – but this isn't enough*

Ricardo Consulting Engineers prediction

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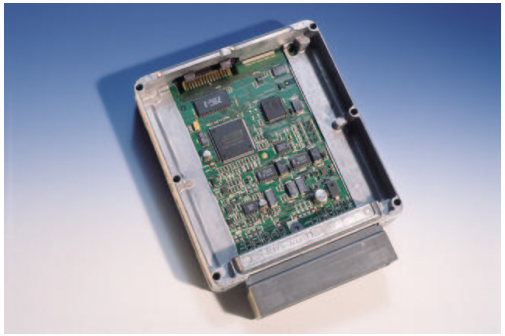
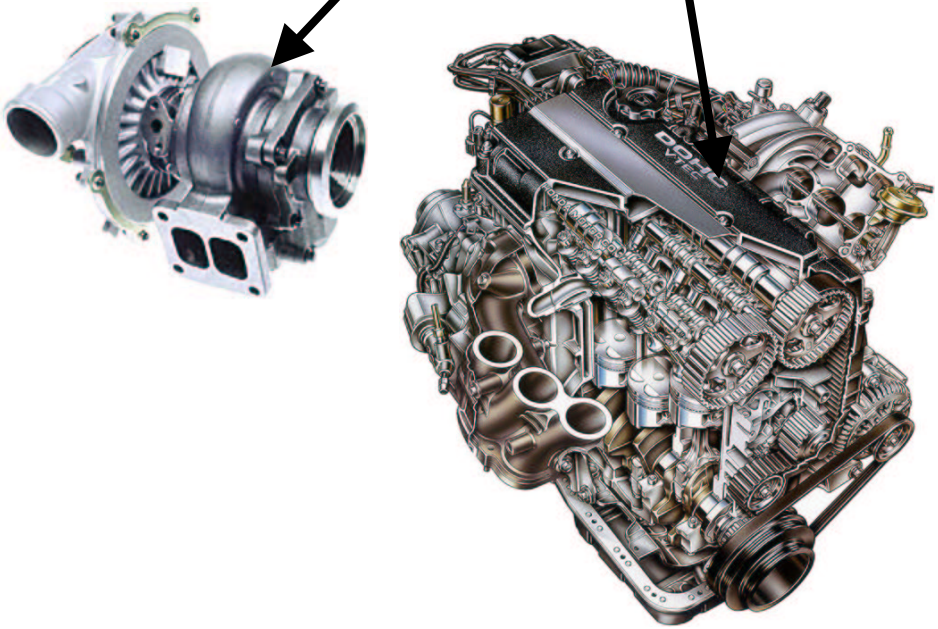
The engines may be controlled in new ways

- *Variable valve timing*
- *Smaller engine with supercharging*



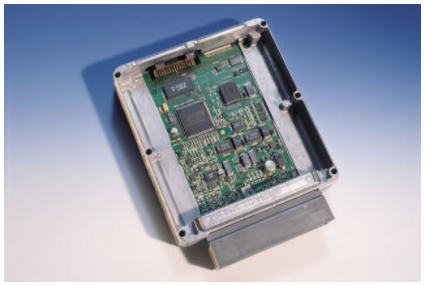


The control system needs about 50,000 parameters to work

The task is complex: mathematically demanding and requiring advances in statistics

Traditional approach to engine management is through peer to peer architecture

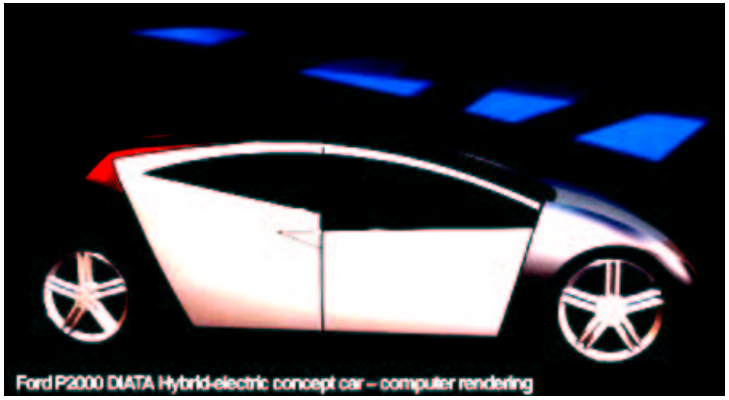
- Individual controls autonomous with some decoupling
- Mid 90s saw the introduction of torque based controls
  - A novel way of co-ordinating the effect of multiple controls
  - A new scheduling technique
  - Not a radical overhaul of controls but a new arcitectural approach that suits new propulsion systems



The HEV is an vehicle whose propulsion power is taken from multiple sources

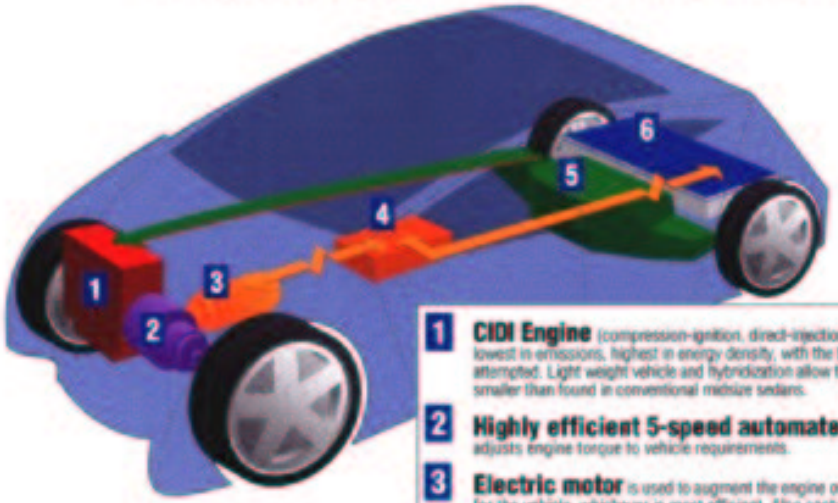
- Propulsion is generally by means of electric motors but may be a combination of engine and motors
- Electricity may be generated by an engine/generator or a fuel cell stack
- Energy is stored in a battery or ultra-capacitor
- The control challenge is in the co-ordinated control of energy flows

What is a hybrid vehicle?



Ford P2000 Hybrid Propulsion System

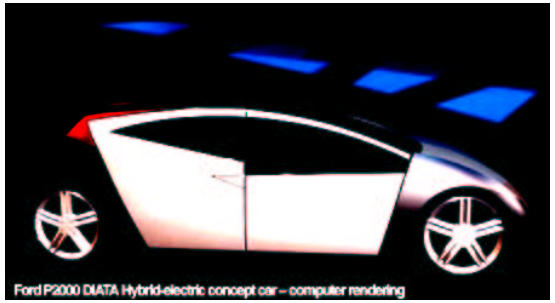
Ford is using what is known as parallel hybrids in its P2000 program. In a parallel system, a heat engine is the primary power source and the electric motor is used as a power assist.



1. **CIDI Engine** (compression-ignition, direct-injection) is believed to be the lowest in emissions, highest in energy density, with the best fuel efficiency ever attempted. Light weight vehicle and hybridization allow the engine to be much smaller than found in conventional midsize sedans.
2. **Highly efficient 5-speed automated transmission** adjusts engine torque to vehicle requirements.
3. **Electric motor** is used to augment the engine or provide exclusive power for the vehicle, whichever is most efficient. Also captures brake energy to recharge batteries. Increases fuel economy and lowers emissions.
4. **Power electronics** controls the flow of electric energy in the vehicle.
5. **Fuel tank** stores liquid fuel to power CIDI engine.
6. **Batteries** are high-power and store electric energy. The batteries dispense energy when necessary to improve efficiency, which aids fuel economy.

Hybrid vehicles – a progression

Microhybrid	*2005*	*Belt driven starter-alternator*
Mild hybrid	*2010*	*Integrated starter-alternator*
Hybrid	*2015*	*Parallel hybrid*
Hybrid	*2020*	*Parallel hybrid with heat recovery*
Fuel cell hybrid	*2025*	



Ricardo Consulting Engineers prediction

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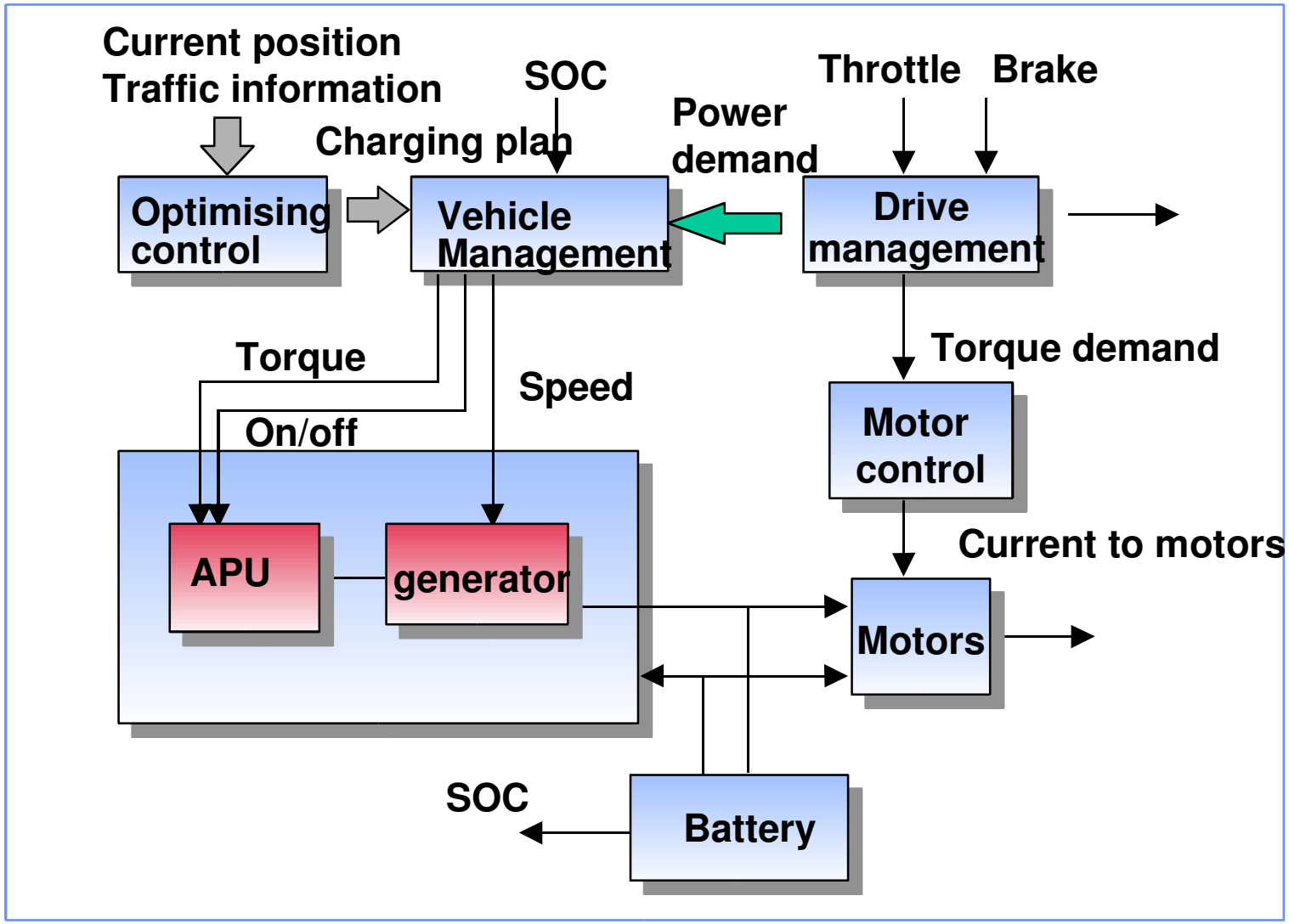
Why hybrid?

- **Multiple energy sources**
  - Primary (from fuel)
  - Secondary (from stored energy)
- **Motivation**
  - Provide an energy buffer to maintain primary source at maximum efficiency
  - Store braking and other “waste” energy

What are the issues with hybrid?

- **Cost of multiple energy sources**
  - Batteries and ultra-capacitors are expensive
- **Cost of power electronics**
  - Power flows must be managed
- **More complex controls**
  - Supervisory systems are needed
- **Design question**
  - What are we designing for? What is the principal duty of this vehicle.



From Waltermann, "Adaptive Energy Management..", IFAC Conference on Advances in Automotive Control, 1998

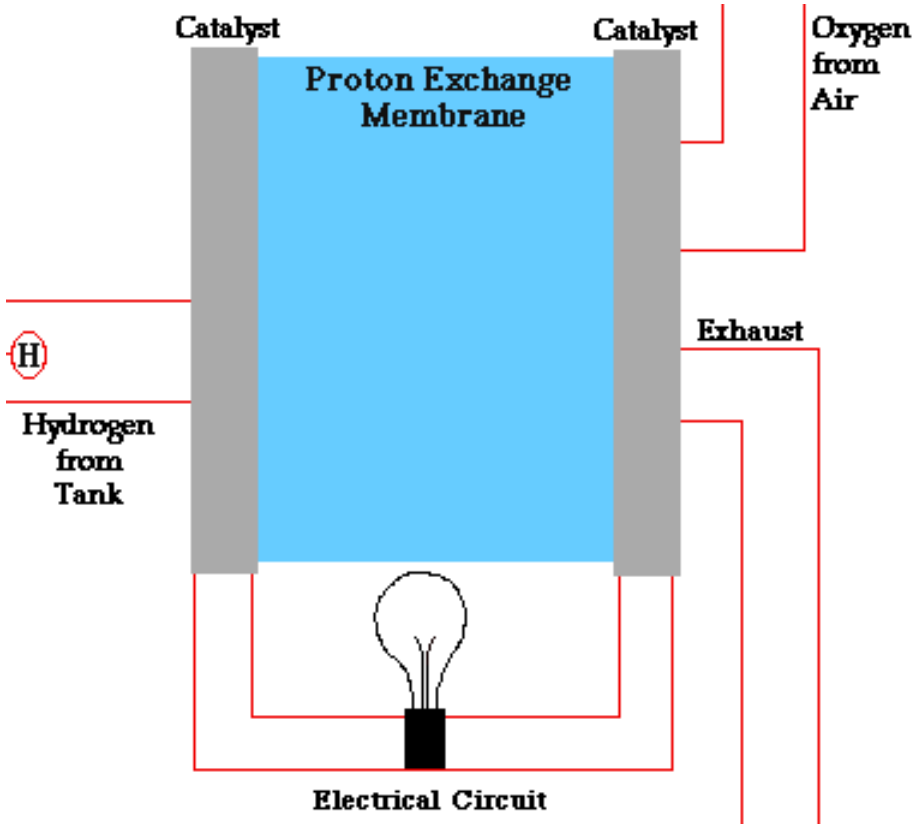
Does the fuel cell have potential as an engine replacement

- **Potentially efficient**
- **Quiet**
- **Non-polluting**

But …

- **Is still very expensive to manufacture**
- **There is a great deal of engineering to do**

How fuel cell technology works …



The fuel cell is a device for making electricity directly from a fuel

Advantages

- *Quick to start*
- *Light weight*
- *Efficient (50-60%) on pure hydrogen*

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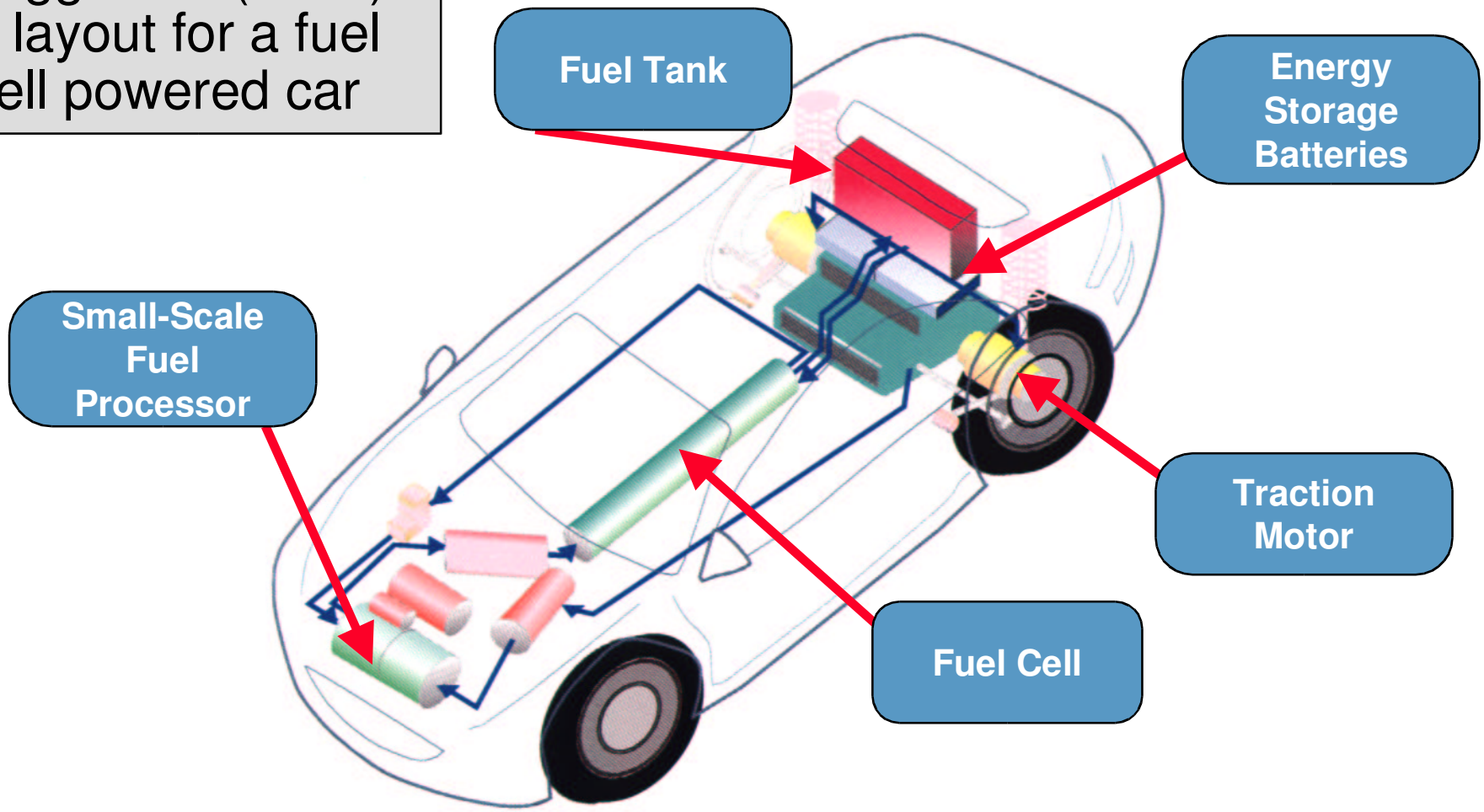
Fuel cells What they look like

This shows the BMW 7 series demonstration car

Source: BMW

What's the shape of a fuel cell car?

Chrysler suggested (1997) a layout for a fuel cell powered car



Fuel Cell Cars

Fuel cell cars have been built but we are only at the end of the beginning

The major challenges

- Hydrogen manufacture and storage
- Making fuel cell stacks more cheaply

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The Technical Issues are only part of the challenge

Refuelling station at the California Fuel Cell Partnership

Public perception of hydrogen …

The reality is quite different …

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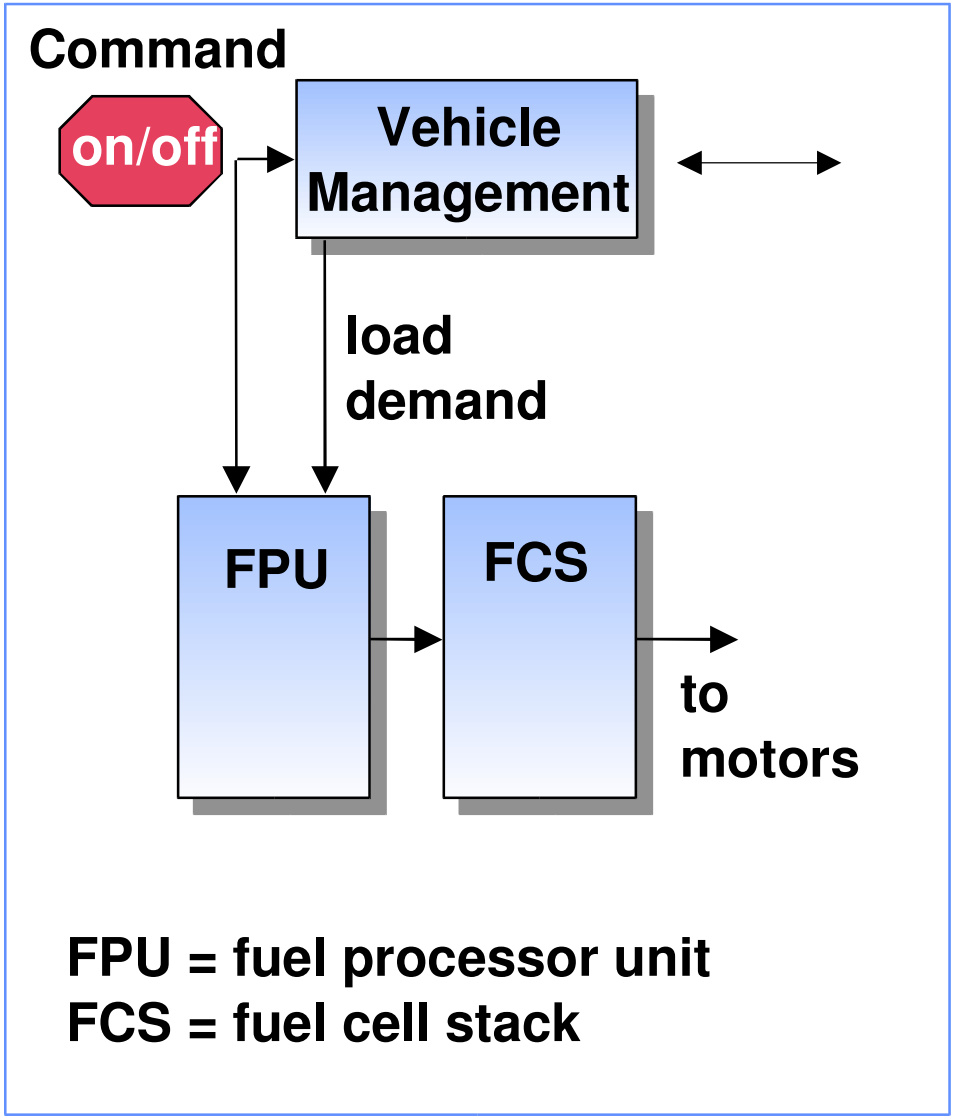
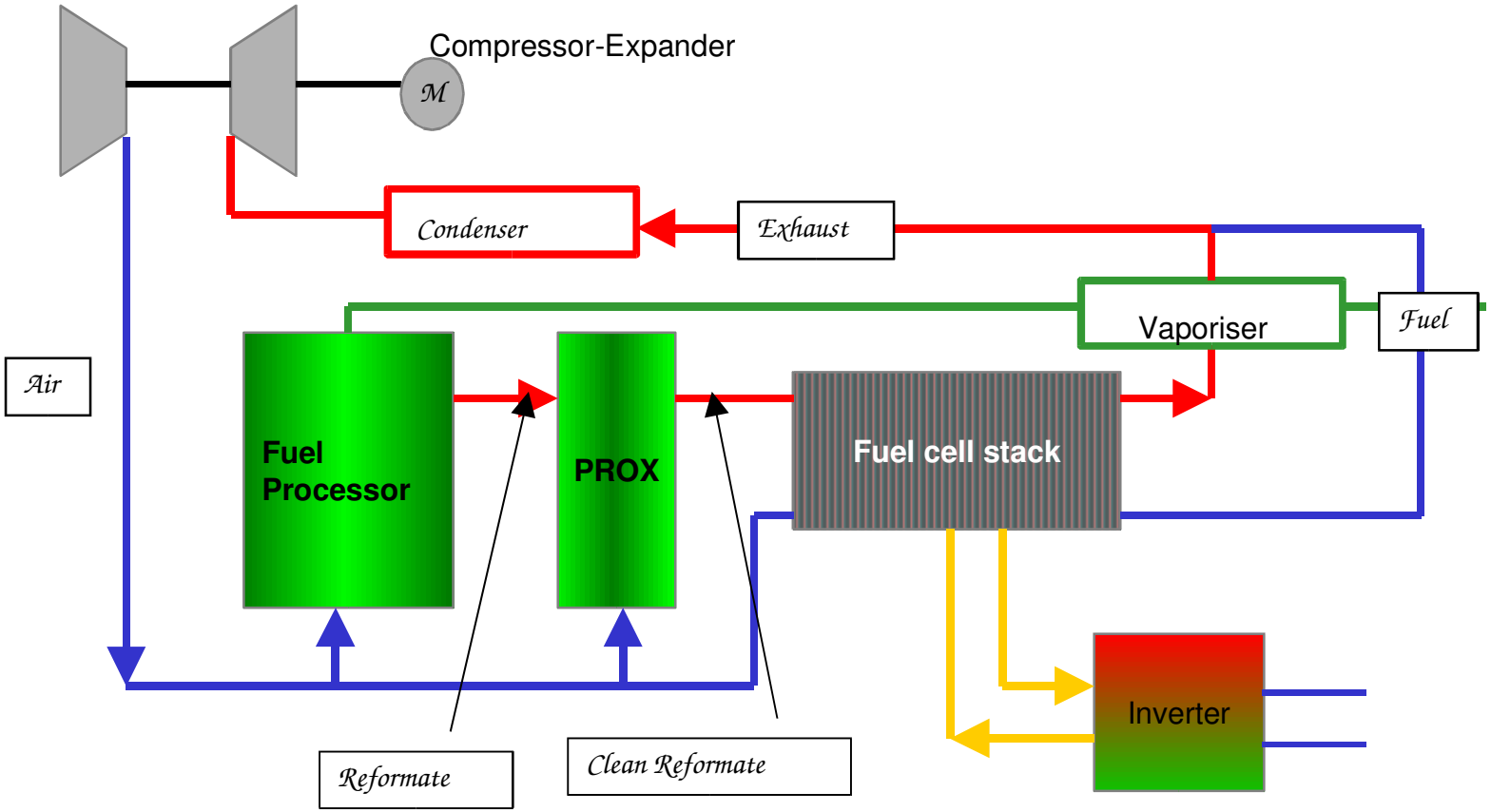
What would a fuel cell car look like?

With a fuel cell the overall architecture remains the same

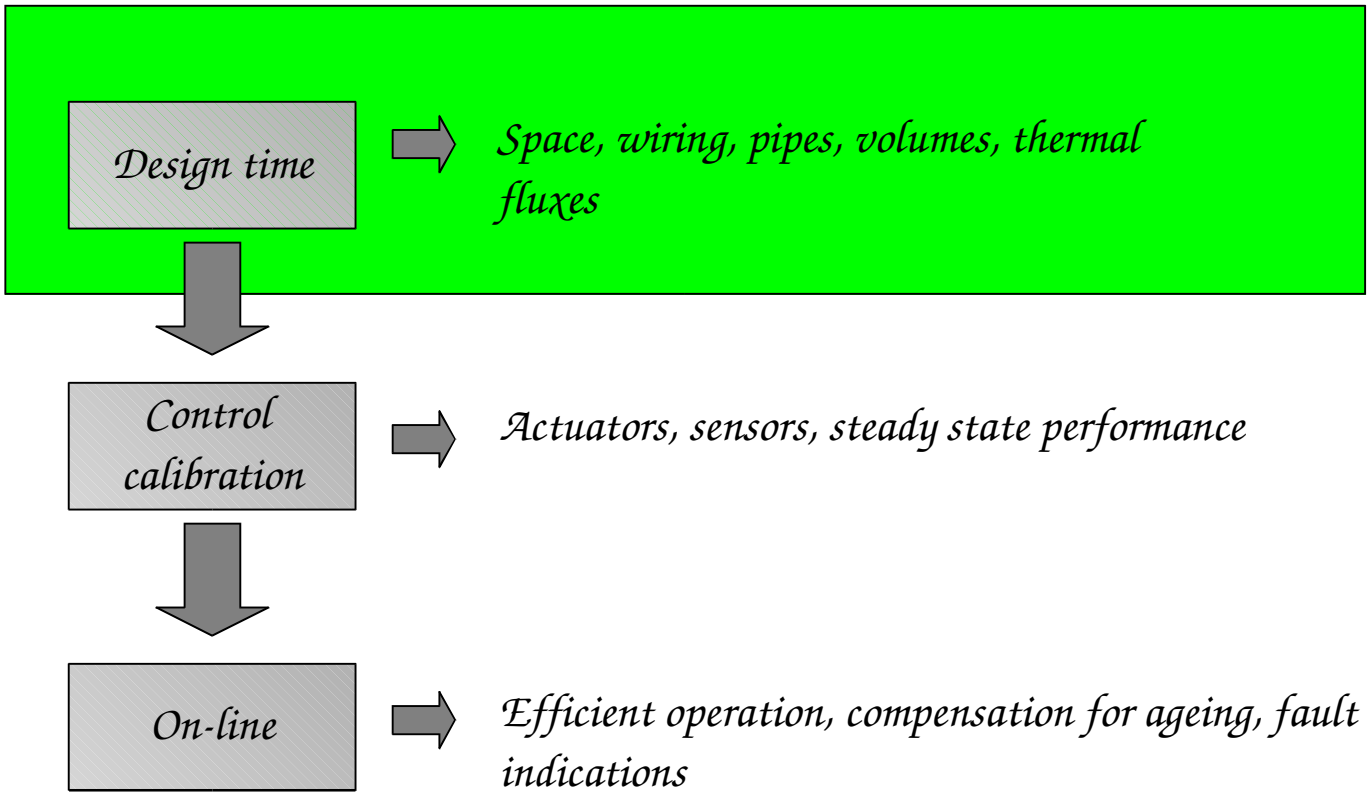
- detailed control of the FPU and FCS is complex but hidden at a component level
- FPU control will borrow from process control techniques
- the FPU will benefit significantly from advance knowledge



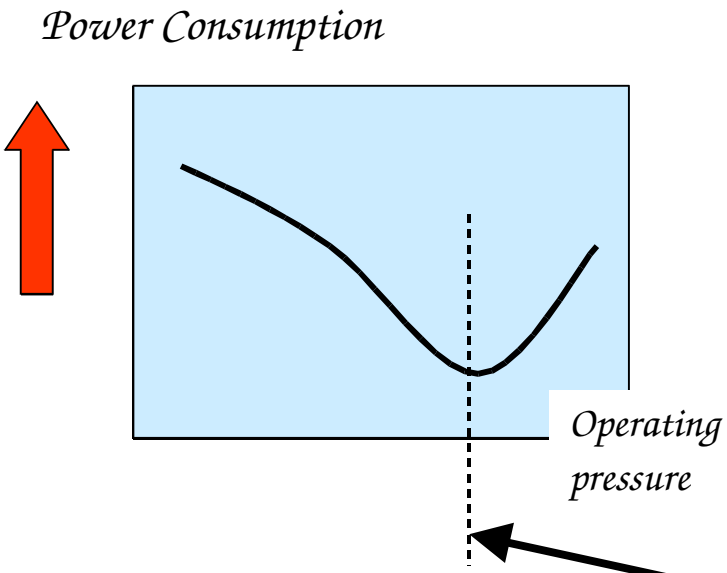
What are we trying to control?



The optimisation process has three clear steps



Optimisation of operating pressure

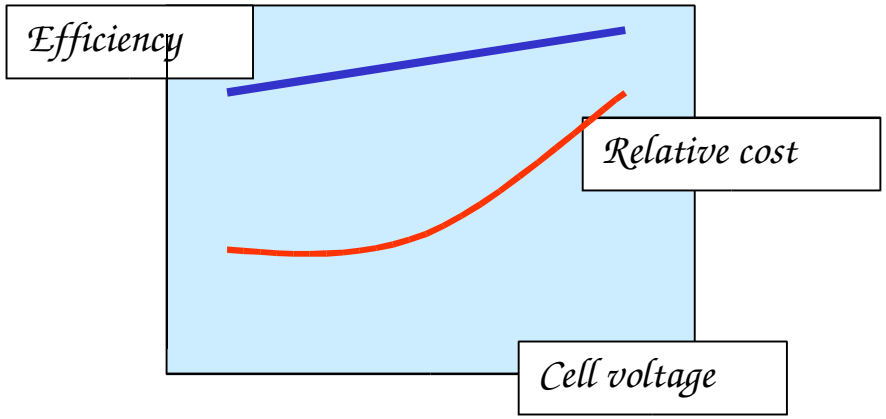


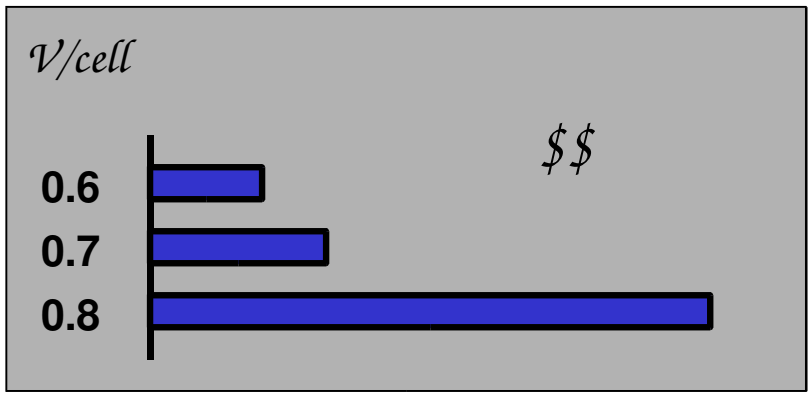
- As pressure increases so does the compressor work
- *Implies* high pressure requires high energy input

- As pressure increases the saturation temperature increases
- *Implies* a reduction in the condenser energy requirement

The two competing effects result in an optimum value

Optimisation of fuel cell stack effectiveness

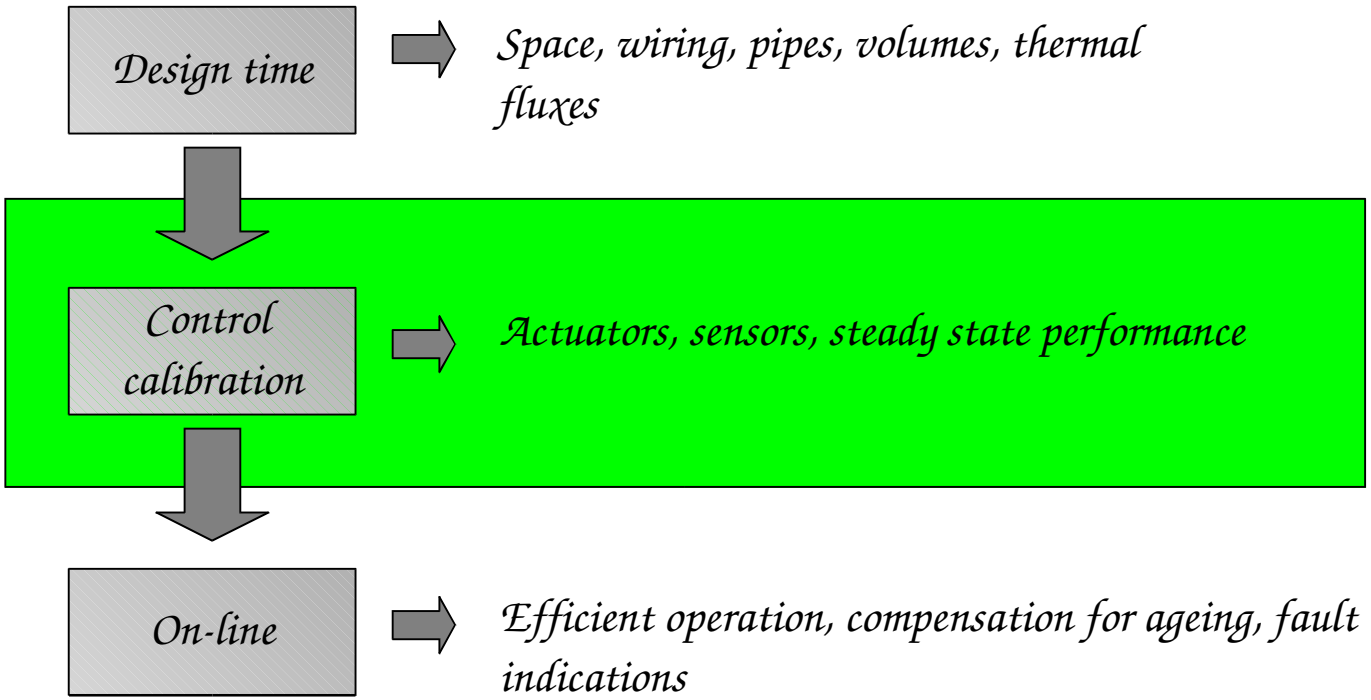




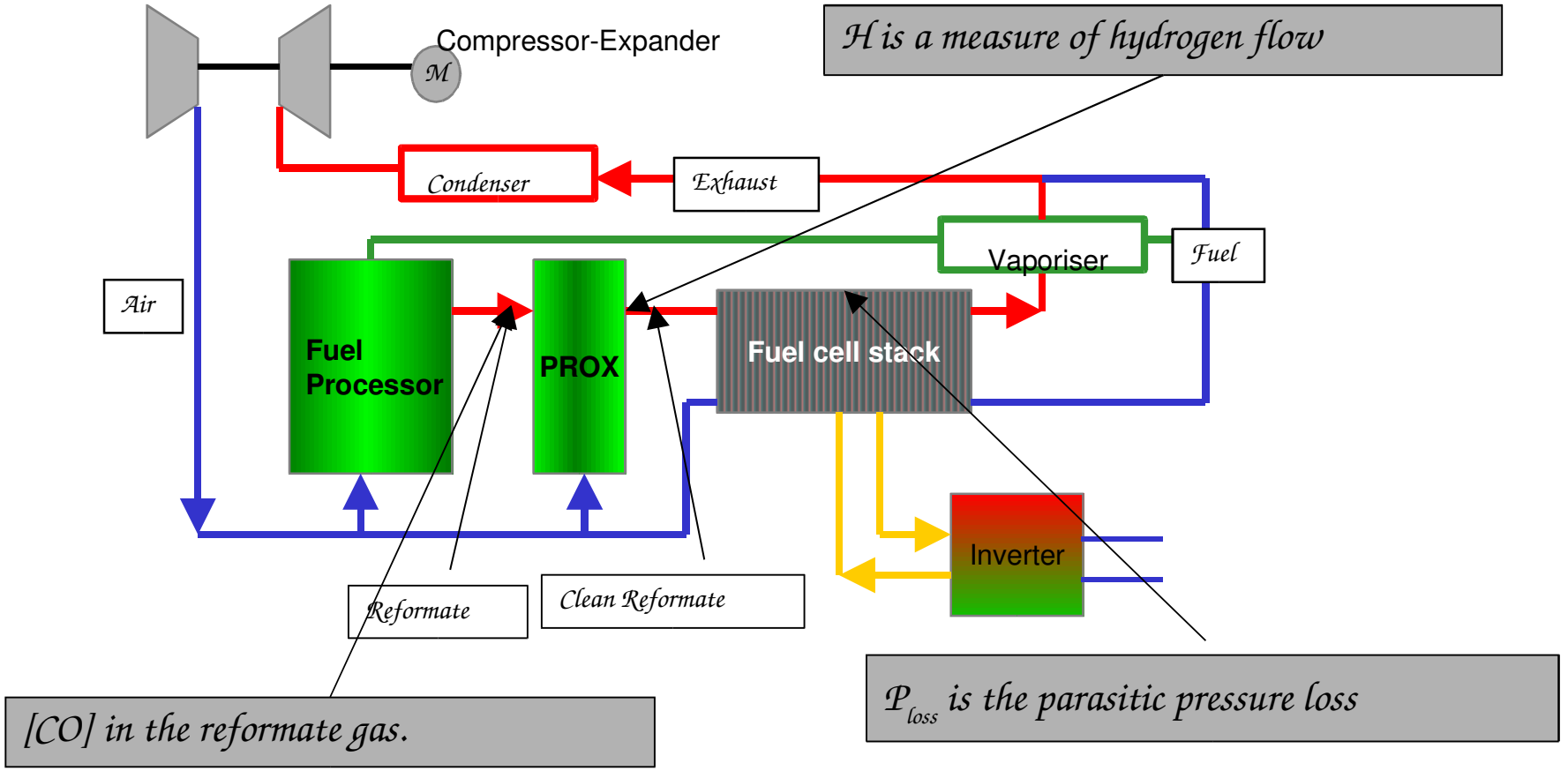
- At low cell currents and high voltages the stack is most efficient
- *Implies* operation at low currents is best
- Cost of the stack is driven primariy by cross sectional area (for a given voltage)
- *Implies* operation at a high currents over a low surface area

There are two competing effects which require a technical and commercial judgement

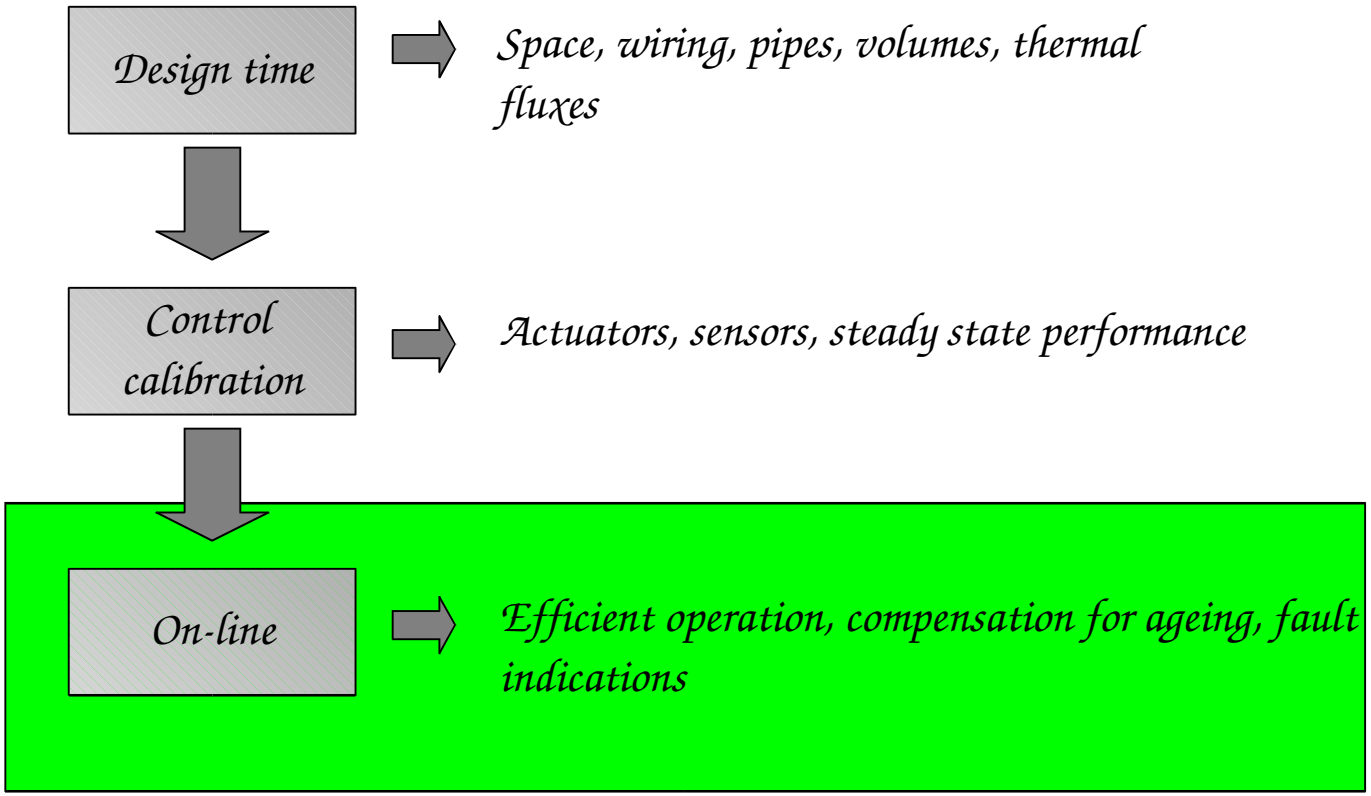
The optimisation process has three clear steps



$$J_{opt} = (P_{loss}^{2} + k_1 f(h) + k_2 [CO])$$

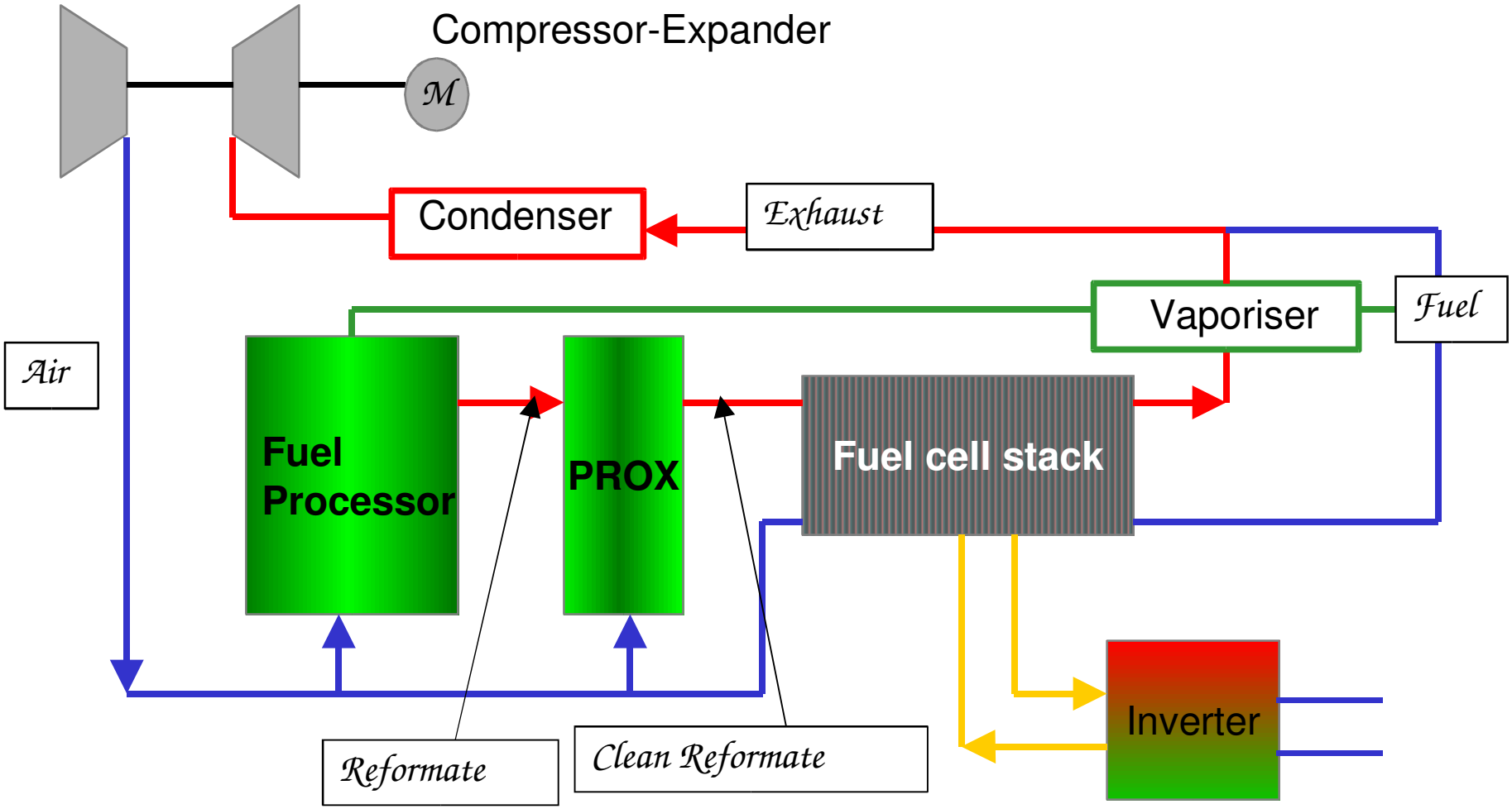


The optimisation process has three clear steps

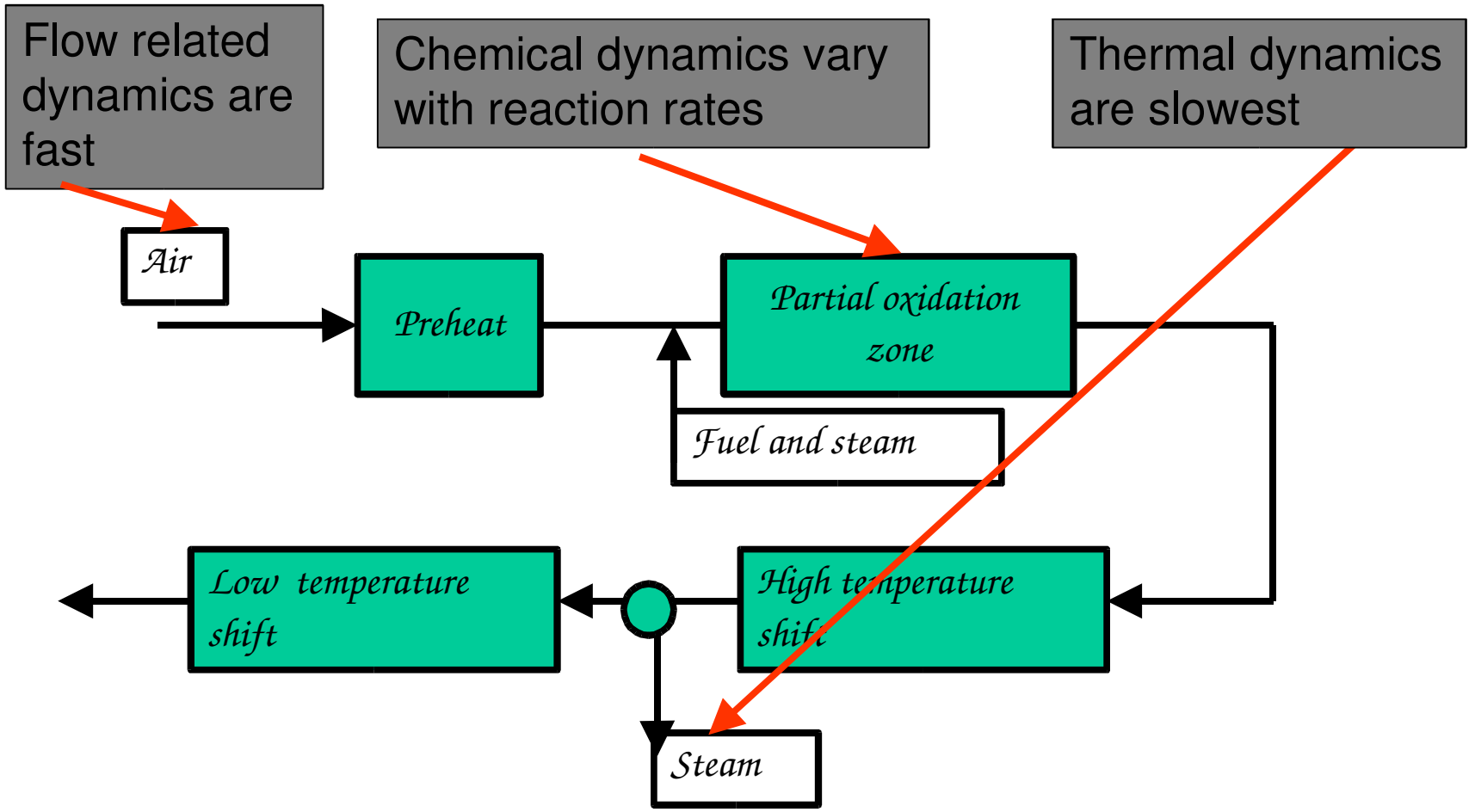


Fuel Cell Background

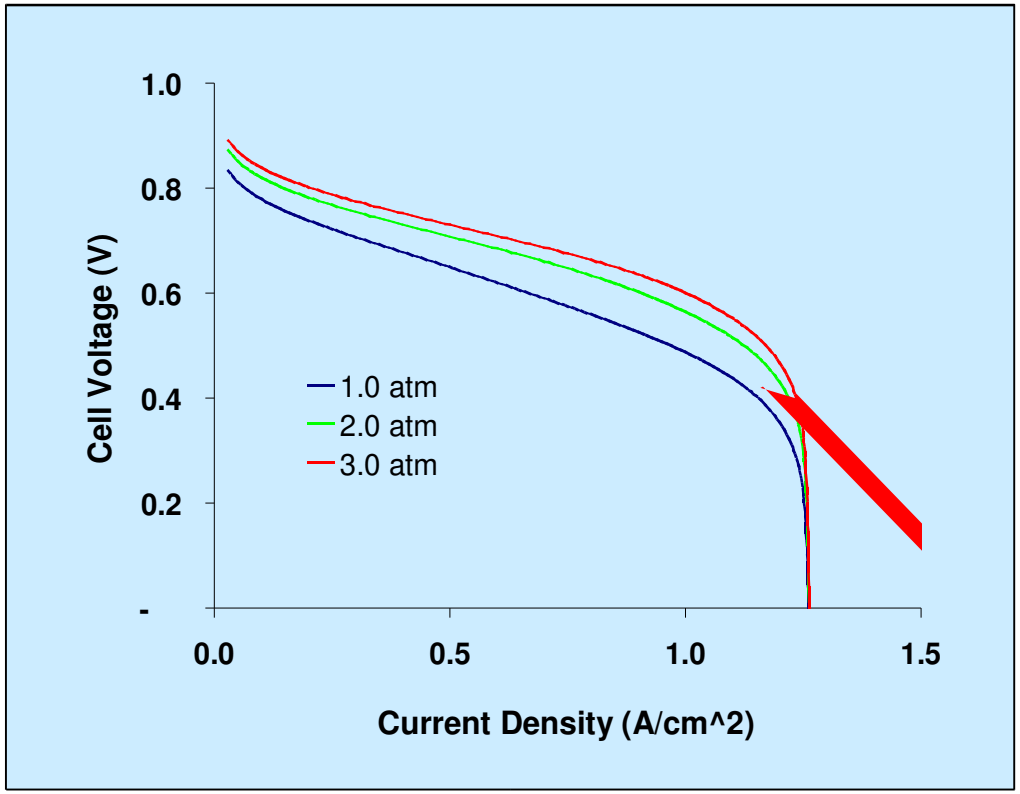
A fuel cell engine is a tightly integrated system design with thermal, air and water management issues



The fuel processor is a device which uses fluid, thermal and chemical effects to convert a fuel to hydrogen



The governing relationship of the stack is the polarisation curve

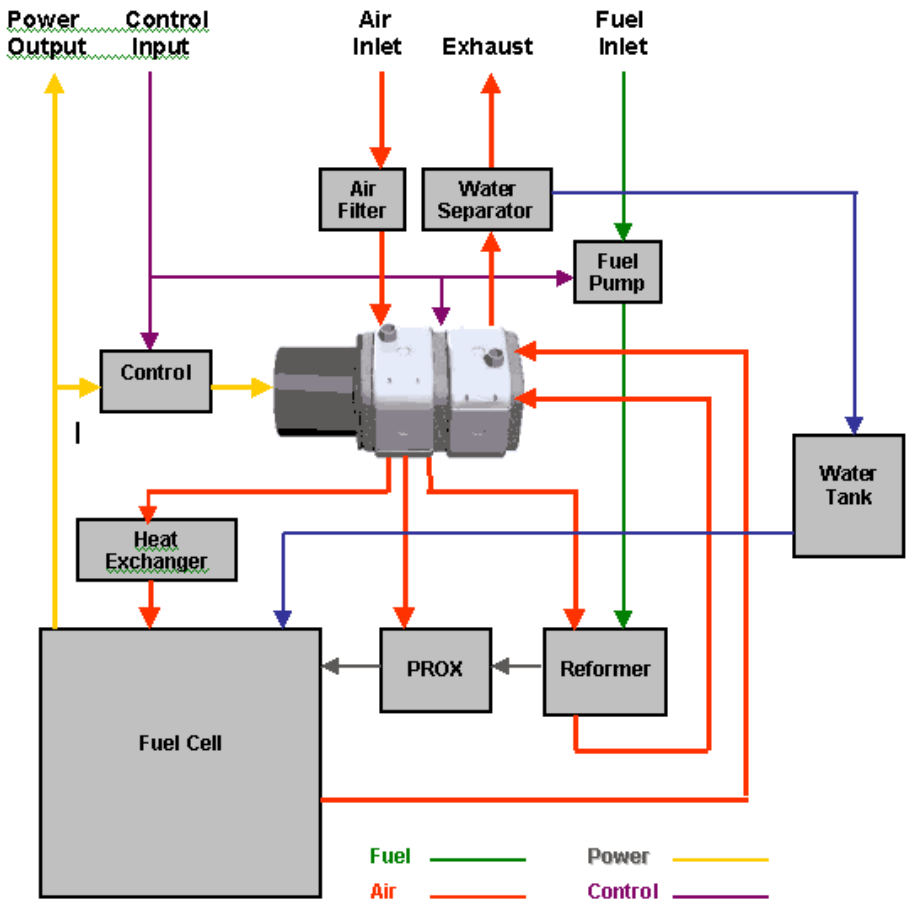


- If fuel gas is present, current is delivered in 10 micro-seconds
- The dominant effect is the supply of gas to the cells

Component Dynamics Air Supply

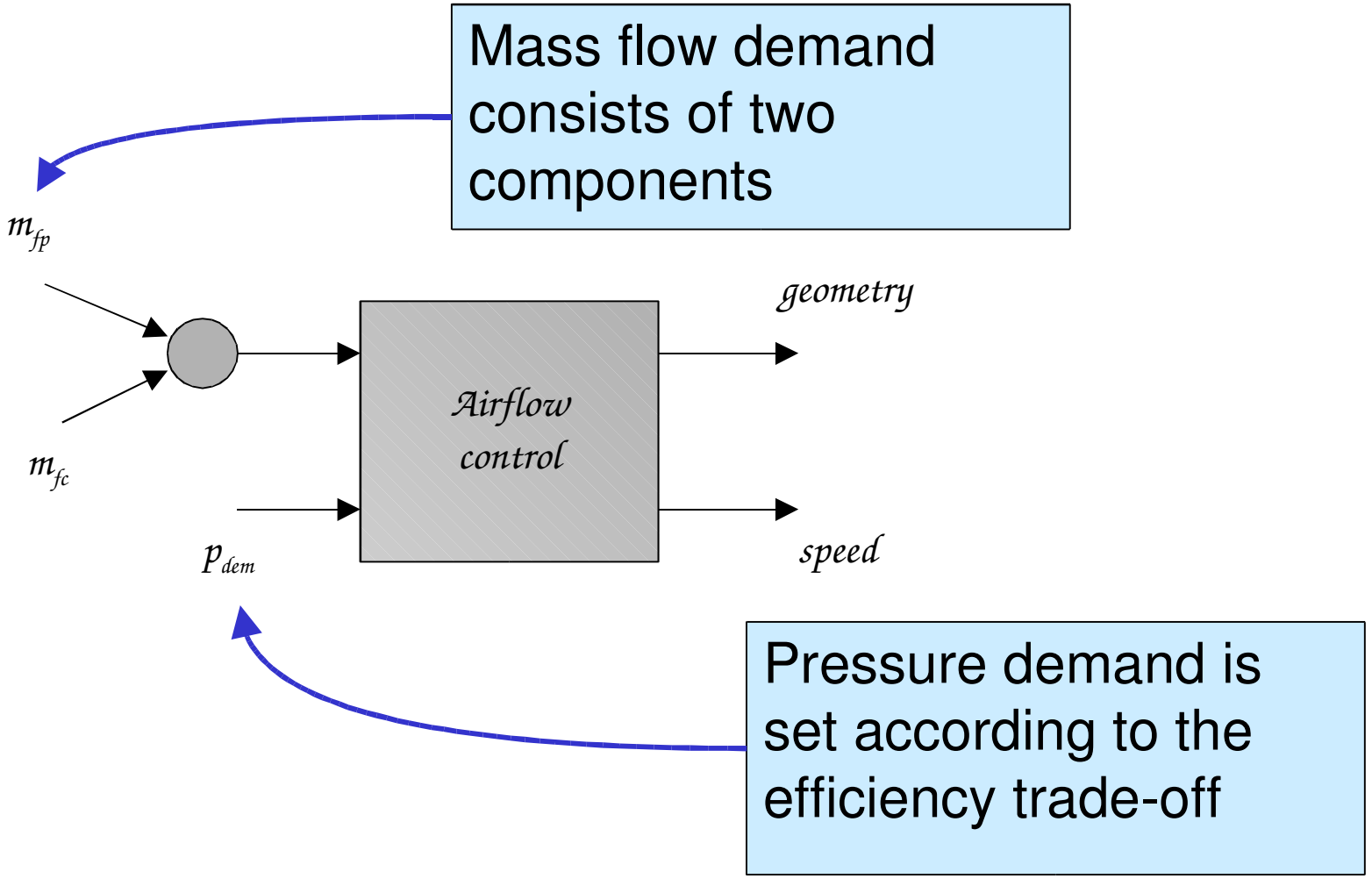
Air supply may be by means of a variable geometry, variable speed device or with valves

- Air supply dynamics are fast, but poor control will be costly
- The air control requirement is multi-variable and requires a *de-coupling* control



Ref: www.vairex.com

Control of air flow



- Current (internal combustion engine) systems will continue to be developed for some time
- Hybrid technology is accepted as being the “bridge” to a hydrogen economy
- Hybrid technology will accelerate the development of new control architectures
- Fuel cell systems will be introduced in power generation before propulsion
- Fuel cell vehicles are now under development and a good control solution will be fundamental to their success

Conclusions

- Fuel cell technology offers significant benefits
  - Low emissions values
  - High efficiencies
- Components are complex and costly
  - Choice of component specification is vital to reaching cost and performance goals
- The fuel cell system contains several such optimisation issues
- Modern approaches to optimisation can help balance cost and performance
- Wholly new approaches to system engineering can (*and should*) be adopted

The end