Fuel Cell APU for Silent Watch and Mild Electrification of a Medium Tactical Truck

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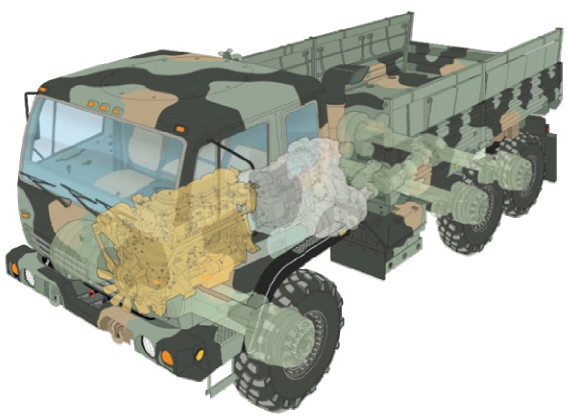
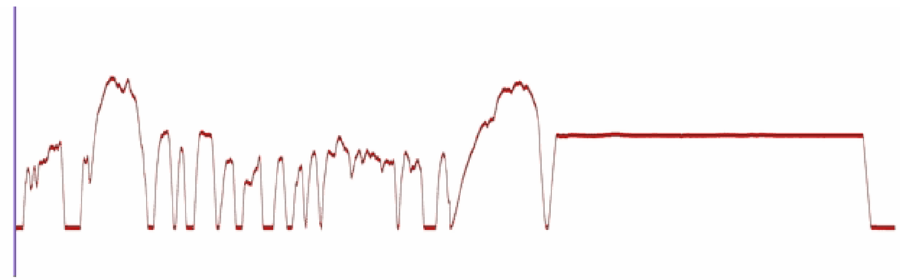
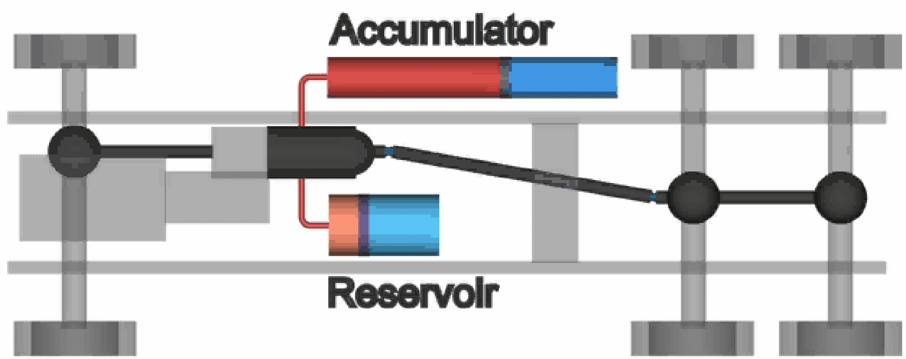
Background

Hybridization of the Family of Medium Tactical Vehicles addressed in the previous ARC study:

Optimal Design and Power Management of the Hydraulic Hybrid 6x6 FMTV enables FE improvement of 31%







FMTV 6x6 truck:

- 7-speed auto transmission
- Total Mass: 15 ton
- 330 hp 6-cylinder engine

Outline

- Motivation
- Silent Watch Loads
- Electrified Accessories; Duty Cycles
- Fuel Cell APU and Vehicle System Modeling
- Discussion of results
- Conclusions

Acknowledgement

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- **ARC Contributors**
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  - George Fadel, Vincent Blouin and Miao Yi (Clemson)
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  - Jim Yakel, Don Szkubiel, Ron Chapp,
Ken Deylami (FMTV PM team);
Herb Dobbs, Erik Kallio (Alternative Fuels & Fuel Cell Team)
Jim Miodek, Fred Krestik (Team Power)
- **Industry Partners:**
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Dave Perry and Walter Budd (Stewart&Stevenson)

Electricity-Hungry Technologies

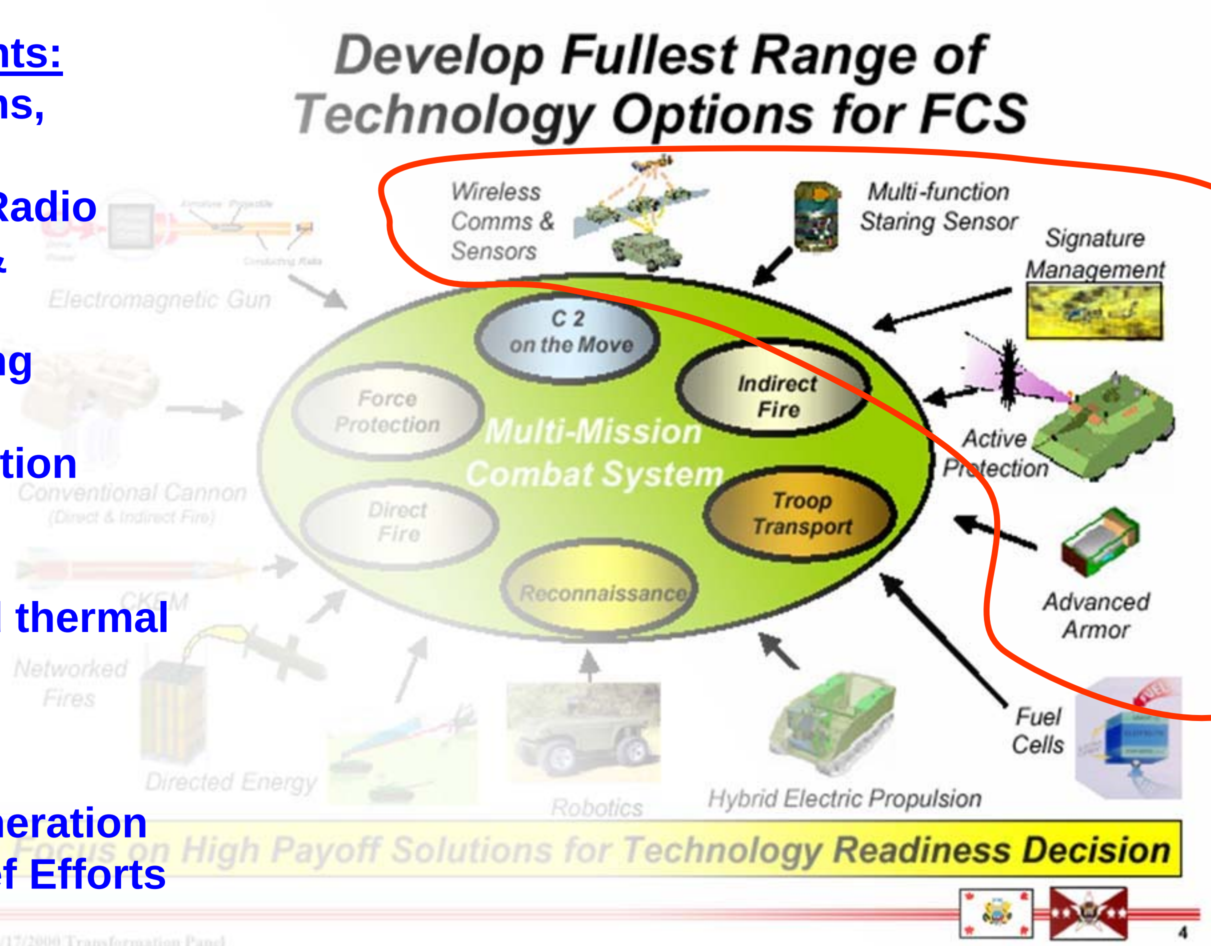
Standby Requirements:
- Navigation systems, GPS, 3D Mapping
- Communication, Radio
- Battle Computer & Displays
- Movement Tracking
- Night Vision
- NBC Cabin Protection

Silent Watch:

Minimal noise and thermal emission

Mission Flexibility:

On-site power generation
Disaster and Relief Efforts



Source: "Army Transformation", Gen. Paul J. Kern

Silent-watch loads – Tactical Truck

- Peak Power Requirements:
  - Electronics = 0.6 kW
    - EPLARS and PLGR navigation systems
    - MTS (Movement Tracking System)
    - DVE (Driver Vision Enhancement)
    - Battlefield computers
  - Radio system = 0.6 kW
  - NBC: overpressurizing the cabin + A/C = 3.4 kW

Silent Watch Support

- Engine Idling (alternator power)
  - –Significant noise and heat generation
  - –Low Fuel Efficiency

- Battery
  - –Limited silent watch duration
    - 3 h @ 1kW, 1 h @ 2.4 kW with only one cranking
    - Needs 6.5 hours to recharge
    - Deep cycling reduces battery life

- Auxiliary Power Unit (APU)
  - –IC engine or gas turbine + generator
  - –*Fuel Cell*

Electrify Engine Accessories

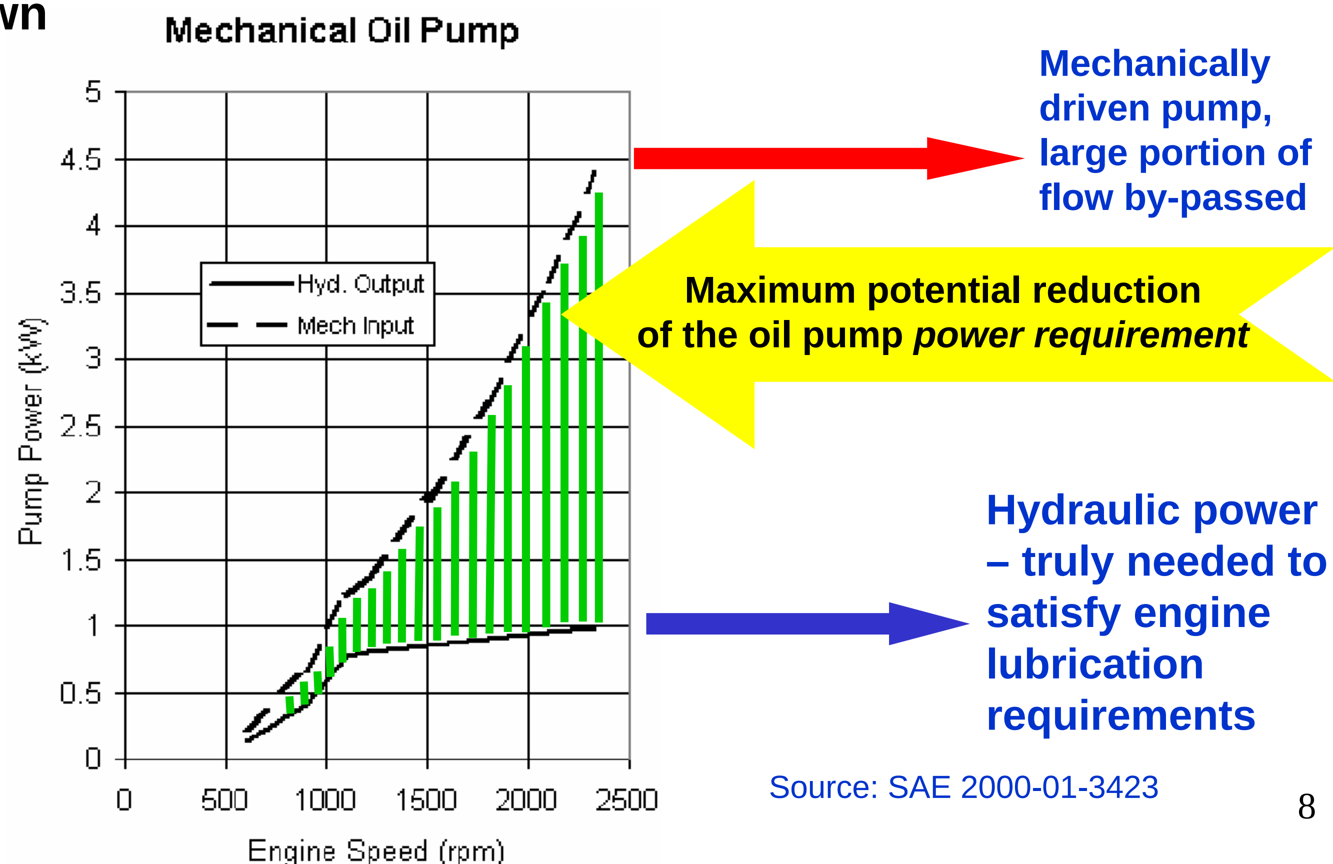
- Significant potential to reduce parasitic losses through electrification of accessories:

➢ **Decouple from the engine, use controllable components**

➢ **Allow engine shut down**

➢ **Run efficiently**

➢ **Downsize engine**



Source: SAE 2000-01-3423

Accessory Loads

- Peak power for mechanically driven accessories
  - Engine fan 26 kW
  - Transmission fluid pump 15 kW
  - Power steering 16.5 kW
  - Air compressor 3.7 kW
  - Engine oil pump 4 kW
  - Engine cooling pump 2 kW

If electrified, the peak requirements are reduced to 6.8 kW total

Total power requirement

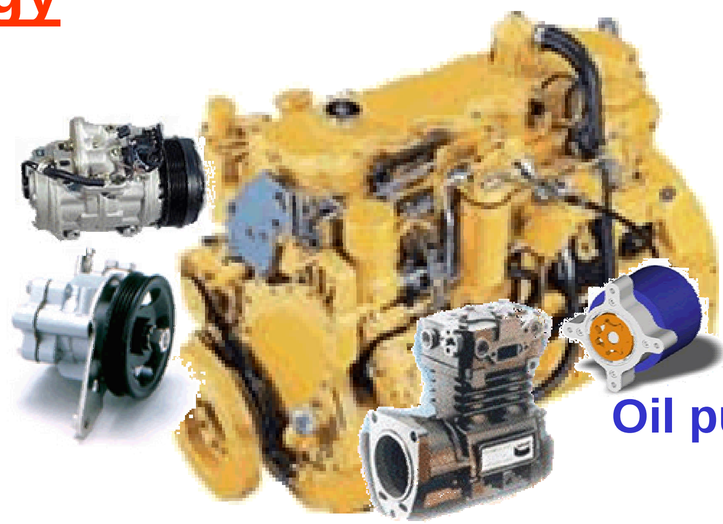
Silent Watch + Electric Accessories = 11.6 kW

Engine and Accessories Architecture

Current technology

AC compressor

Power steering pump

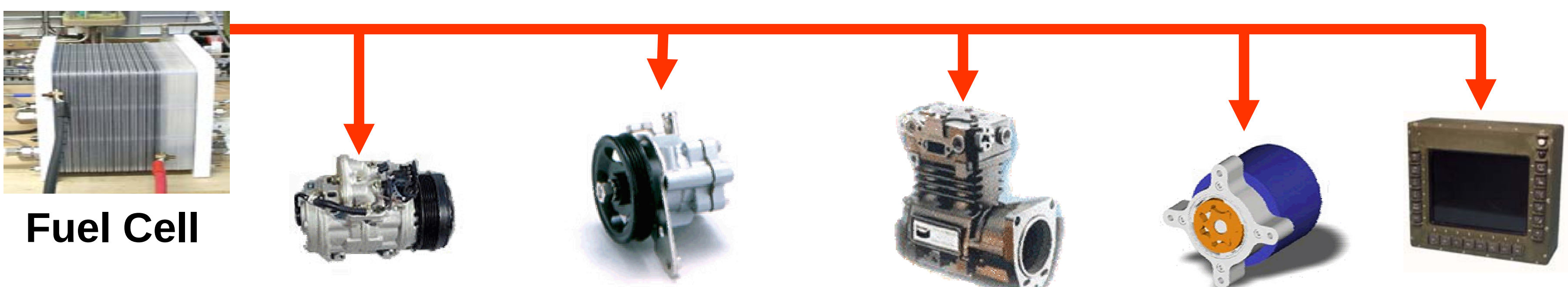


- Mechanical coupling with engine speed
- High parasitic losses

Oil pump

Air compressor

Fuel Cell APU system



Fuel Cell

AC compressor

Power Steering Pump

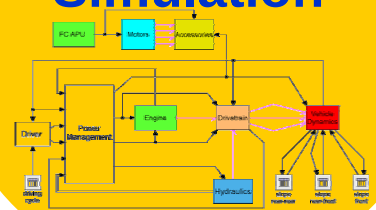
Air compressor

Oil pump

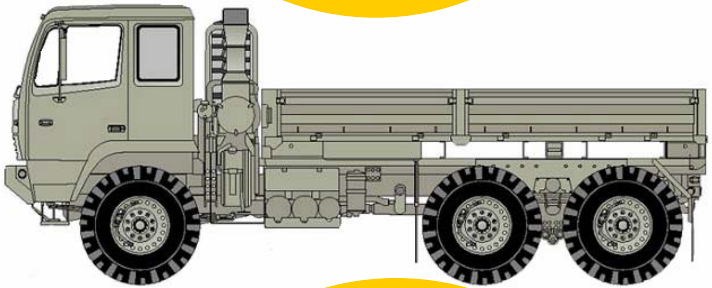
Electronics

Study Enablers

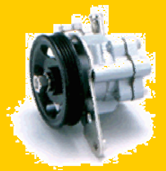
Integrated Vehicle System Simulation

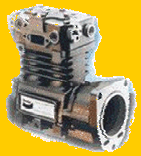


Fuel Cell APU Model

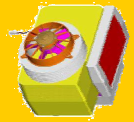


Accessory Duty Cycles





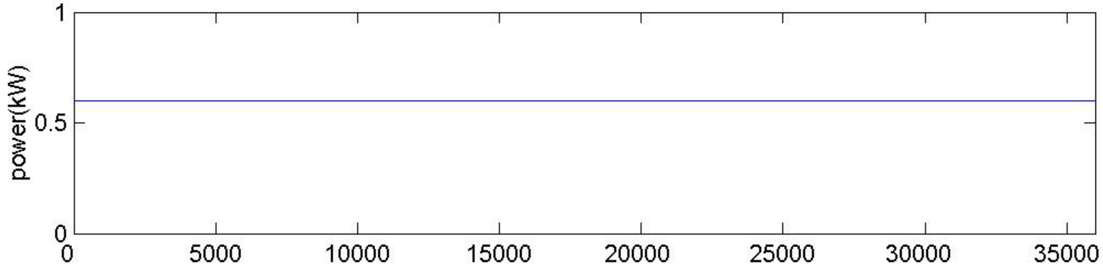
Silent Watch Loads



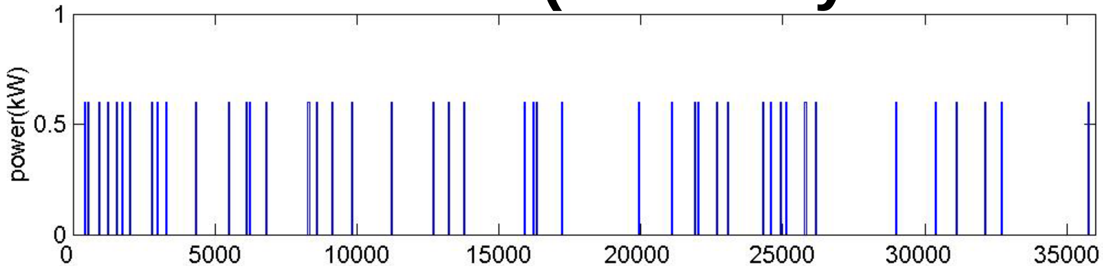
Accessory Loads and Duty Cycles

Silent-watch Loads

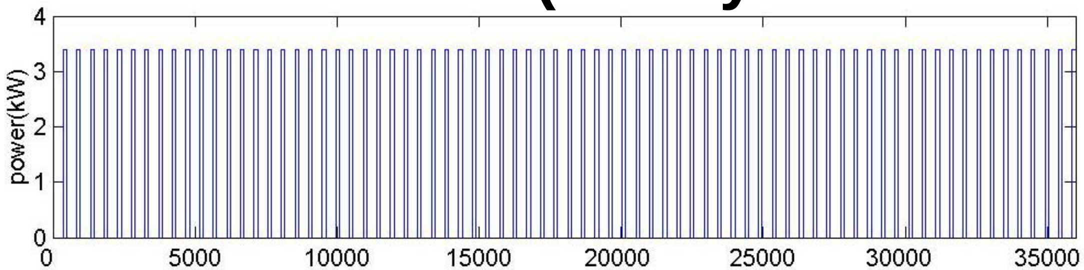
Electronics load = 0.6 kW constant



Radio load = 0.6 kW (randomly distributed)

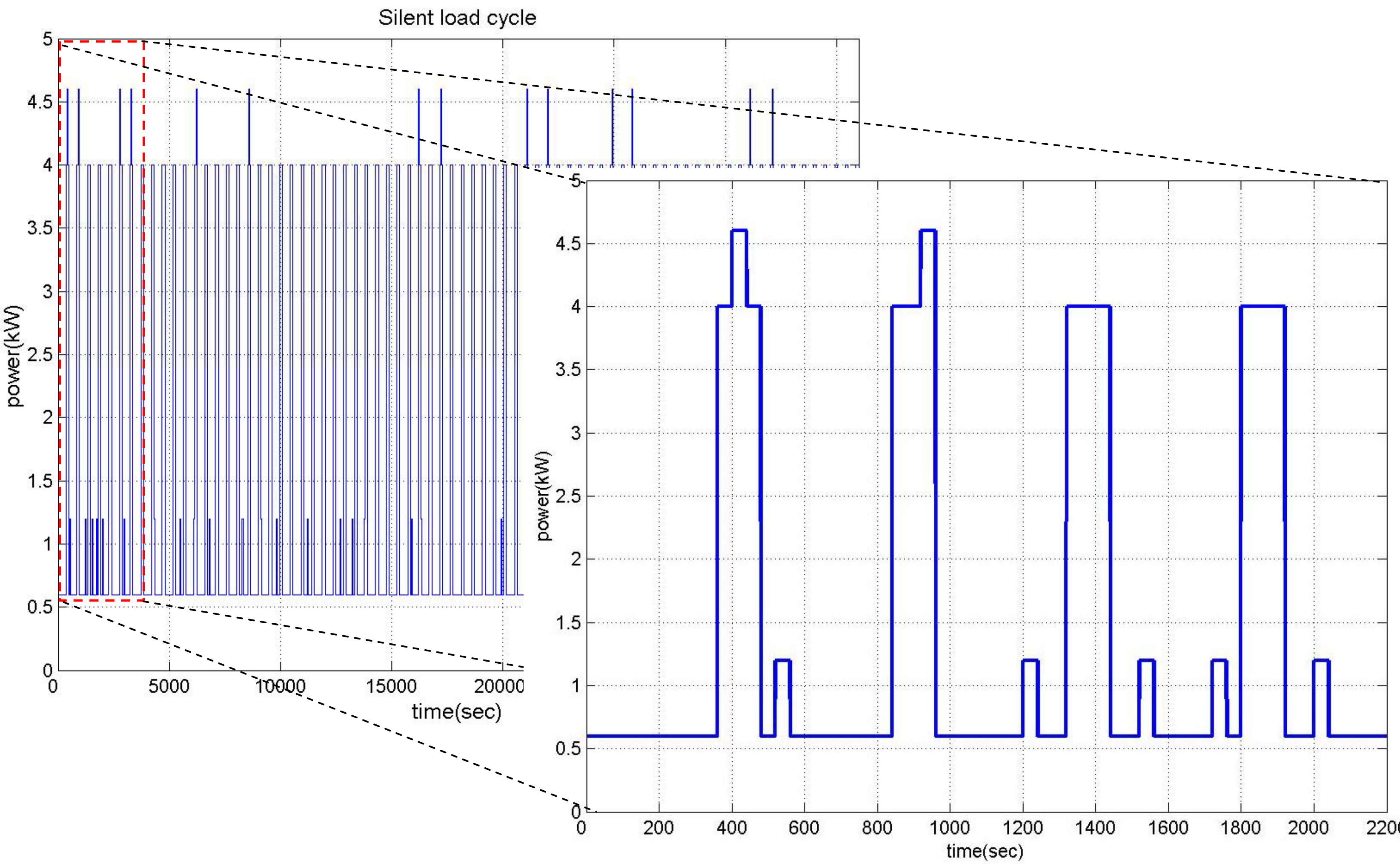


A/C load = 3.4 kW (evenly distributed)

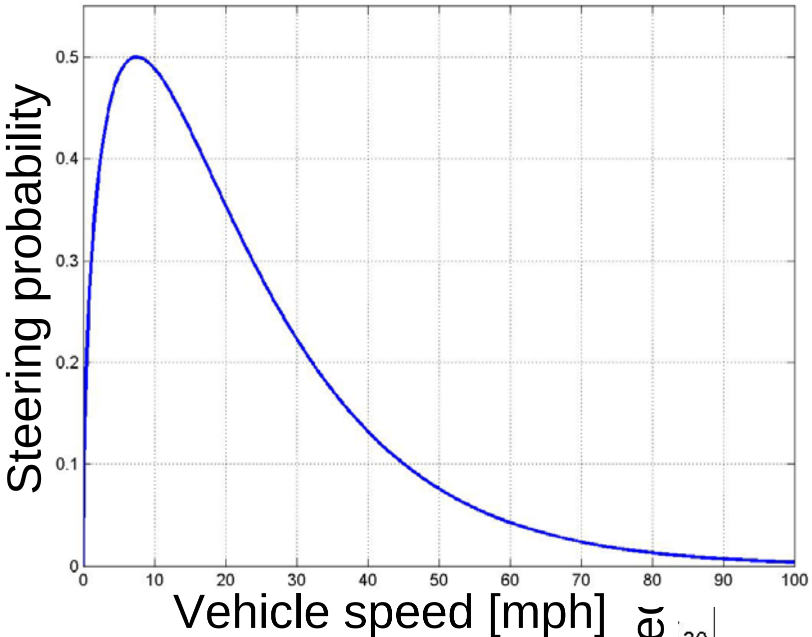


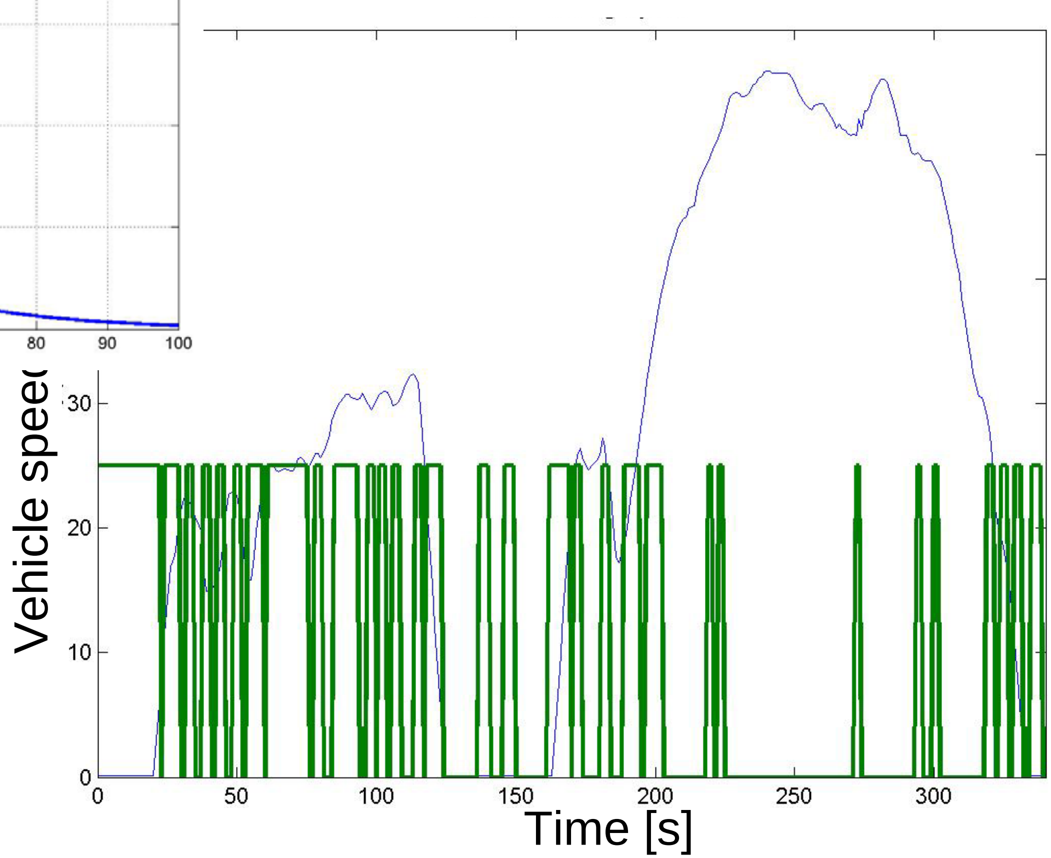
Cycle duration = 10 hours

Silent-watch Loads Combined

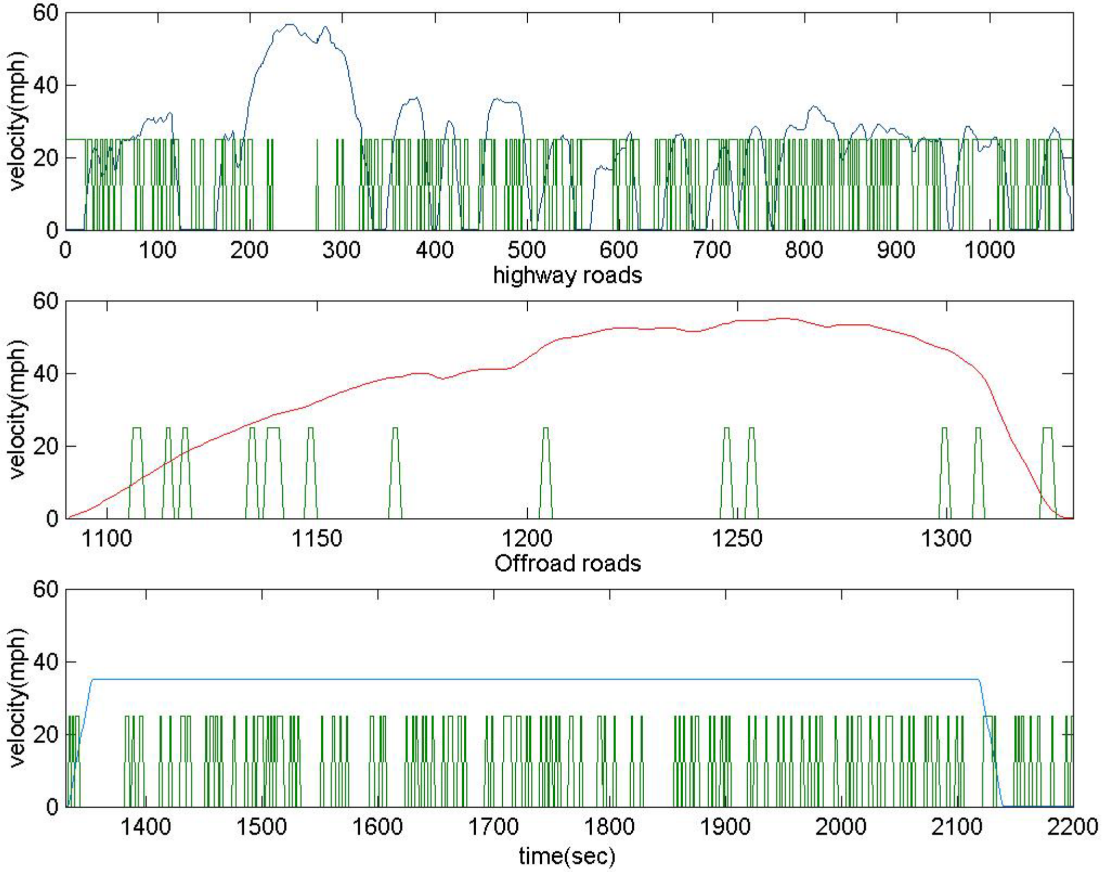


Power Steering Usage





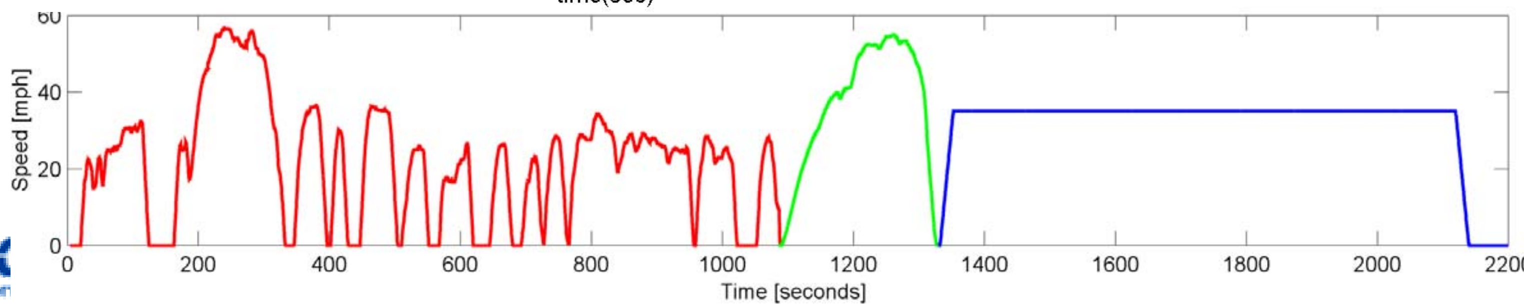
Power Steering Duty Cycle



Secondary Roads : 50 %

Highway: 15 %

Offroad: 35 %



Modeling and System Integration

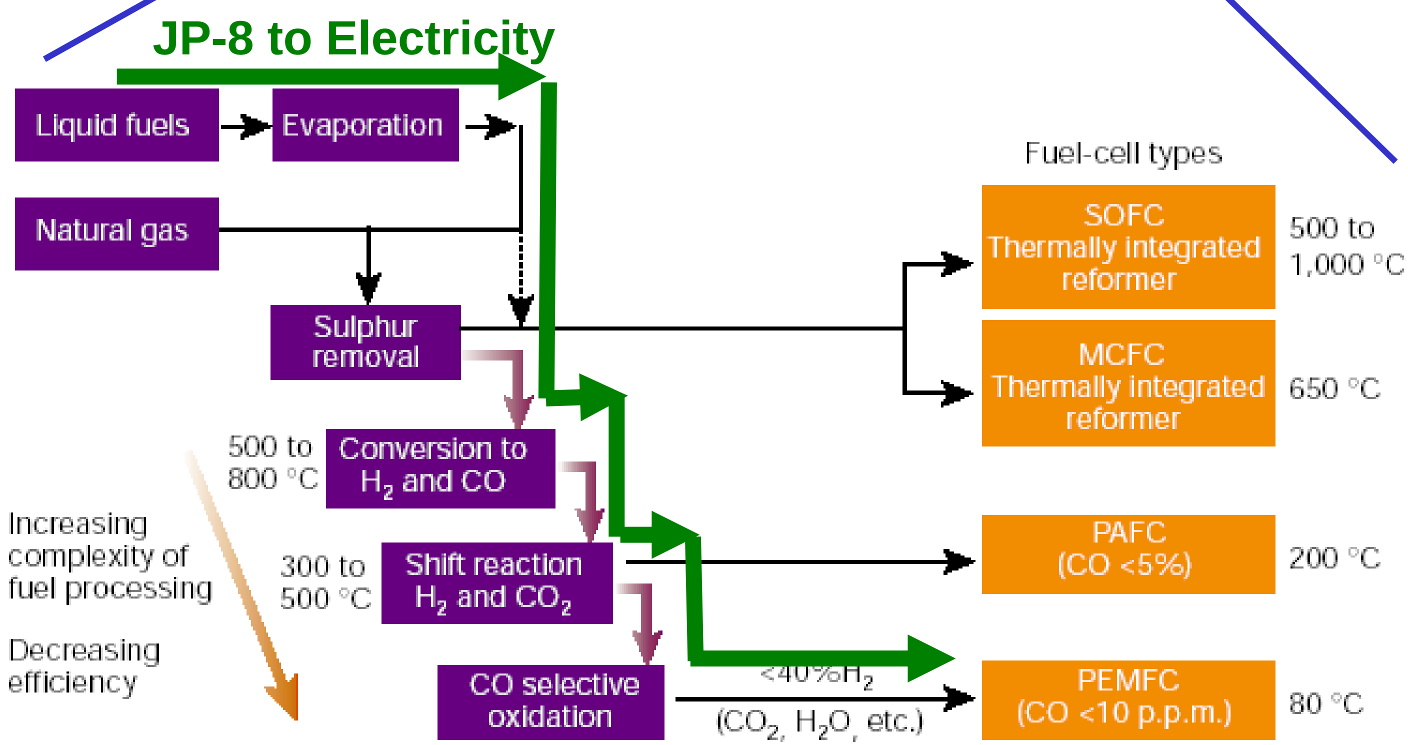
Fuel Cell Auxiliary Power Unit (FC-APU)

Direct H_2

Electrolyser

- **Solar**
- **Regenerative**

Fuel Processor

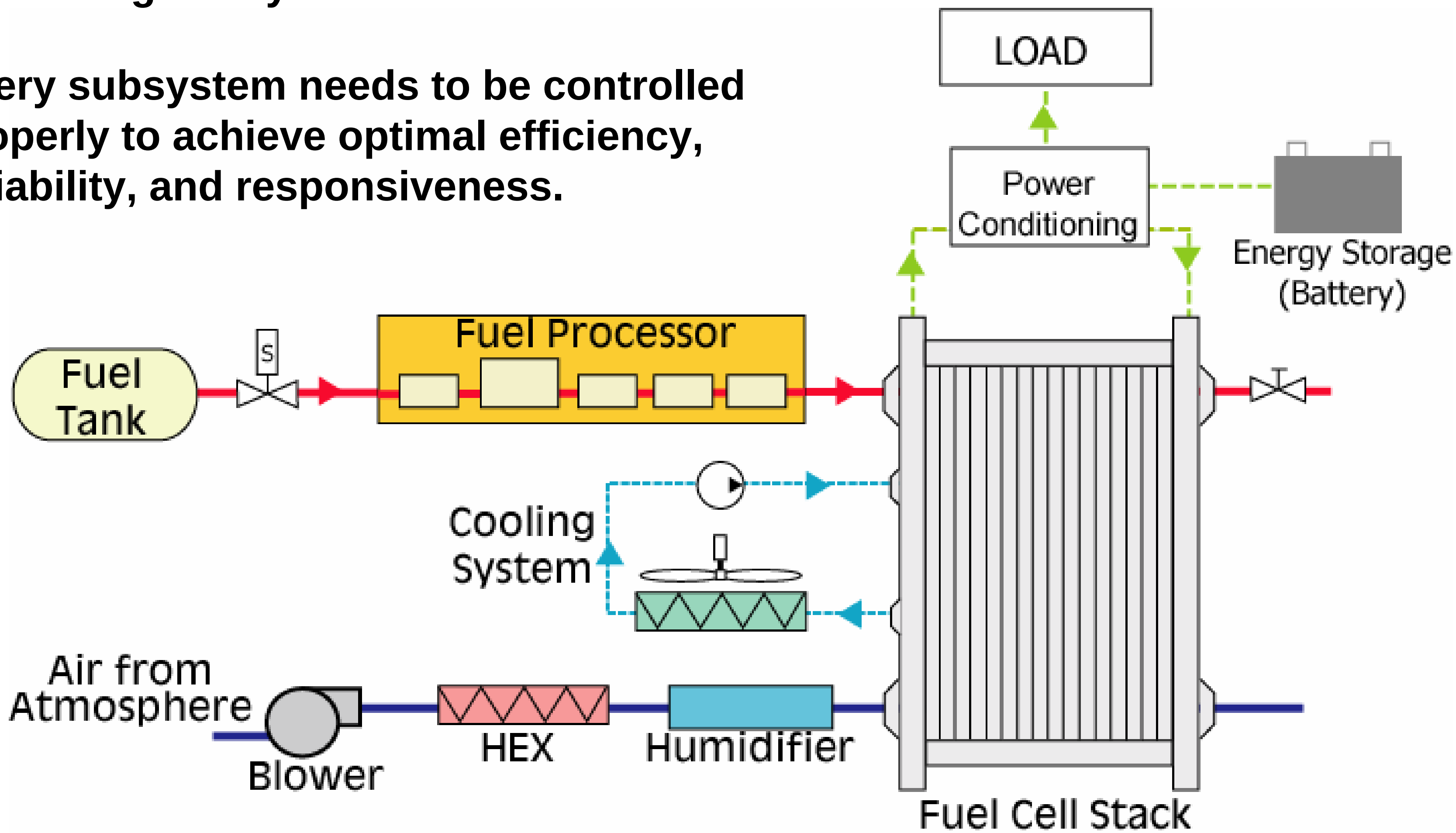


Source: *Nature* 414, 2001

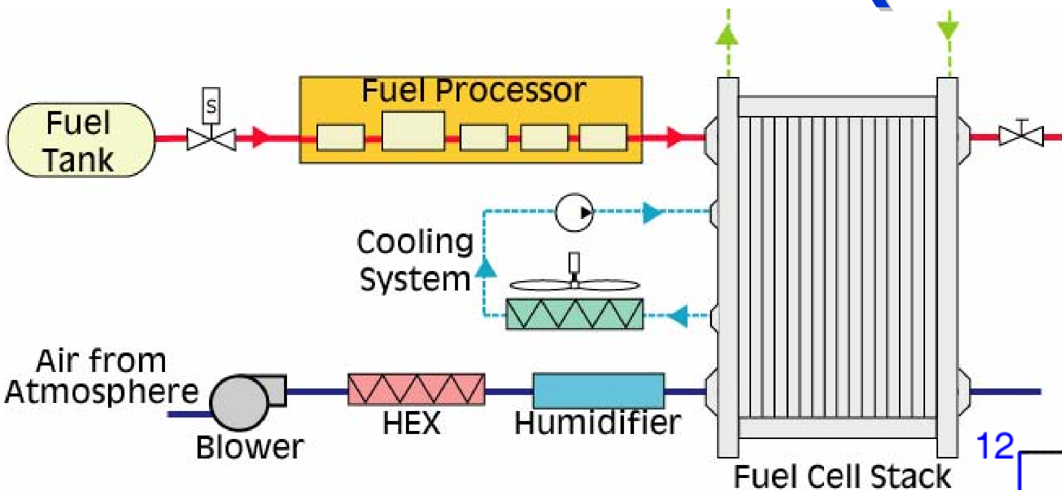
Fuel Cell Power Unit

The Fuel Cell Power Unit consists of many interacting subsystems.

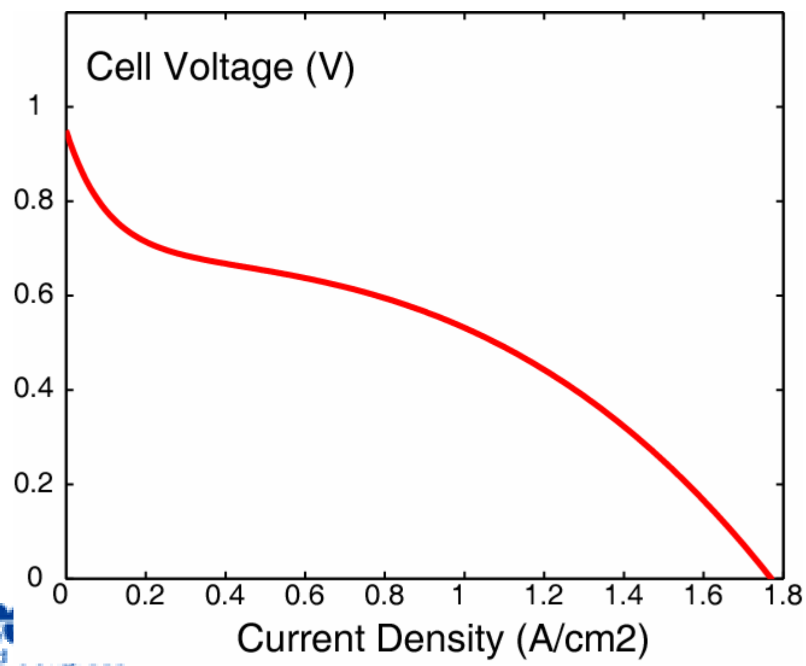
Every subsystem needs to be controlled properly to achieve optimal efficiency, reliability, and responsiveness.

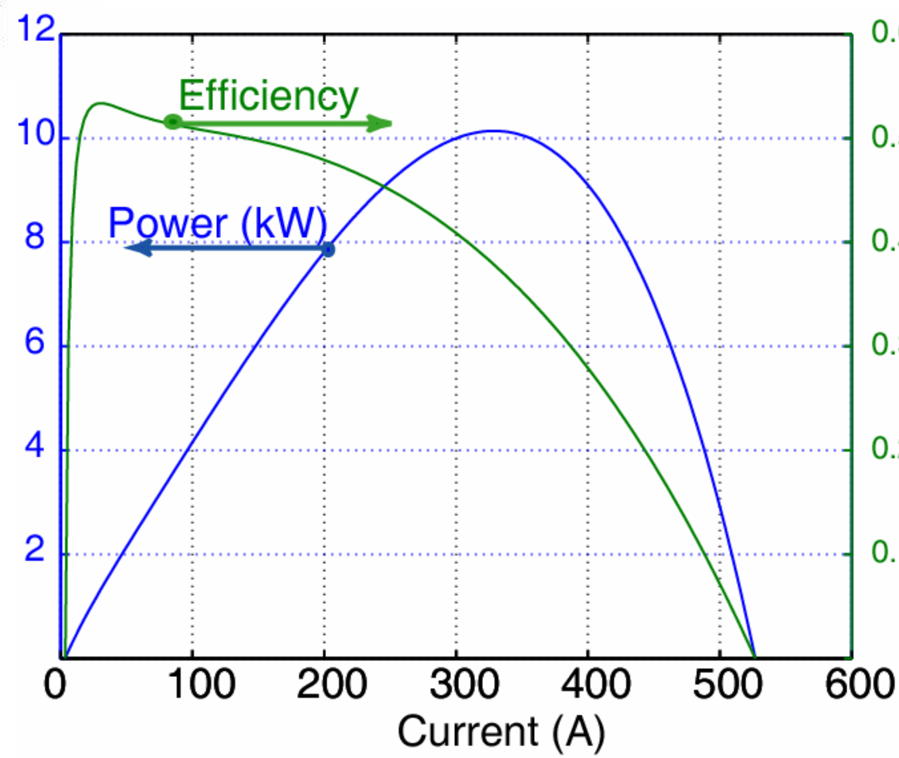


Fuel Cell Stack (FCS) & Auxiliaries



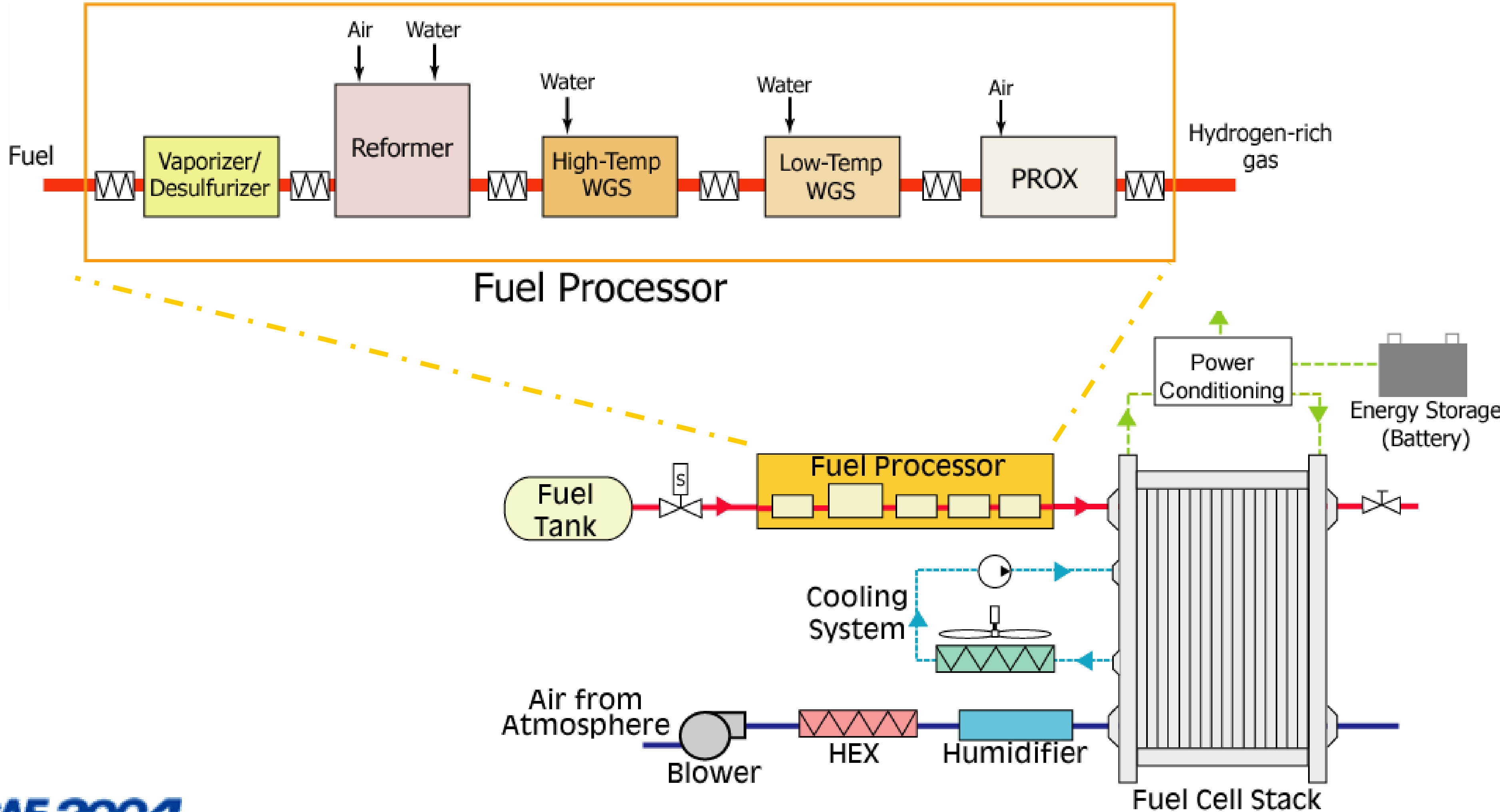
Low Pressure Fuel Cell Stack (10 kW) [300 cm2, 65 cells]



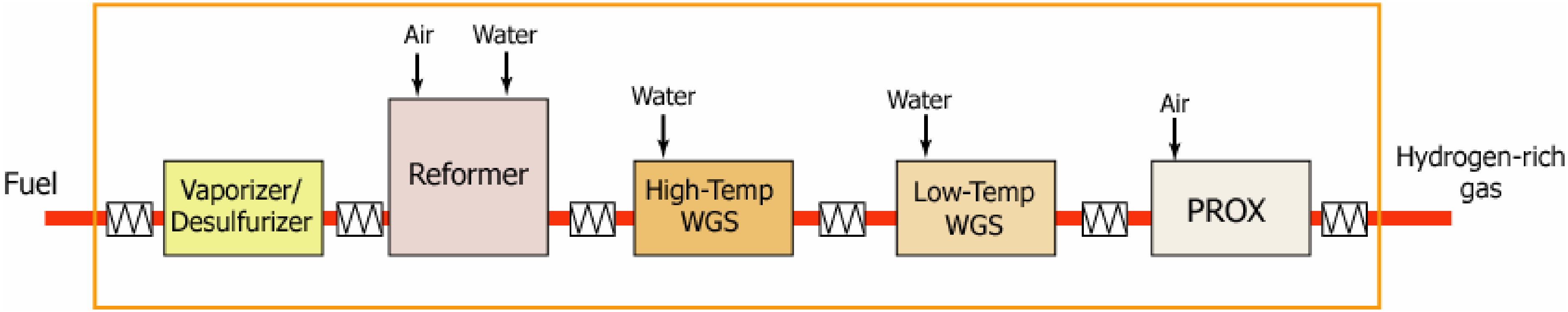


Fuel Processor System

The Fuel Processor System is one of the Critical Enabling Technologies



Fuel Processor (FP)



Control

- Fuel, air and water flow rate

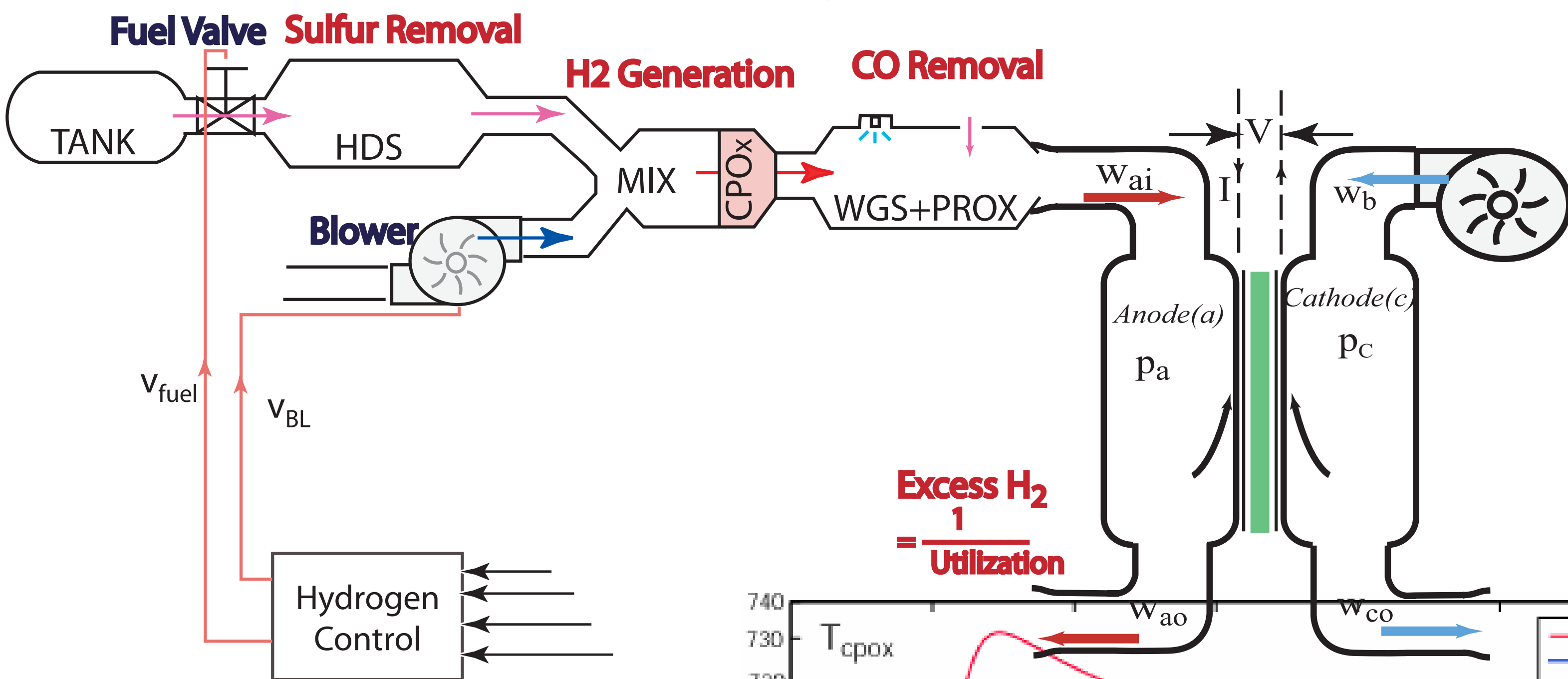
To maintain

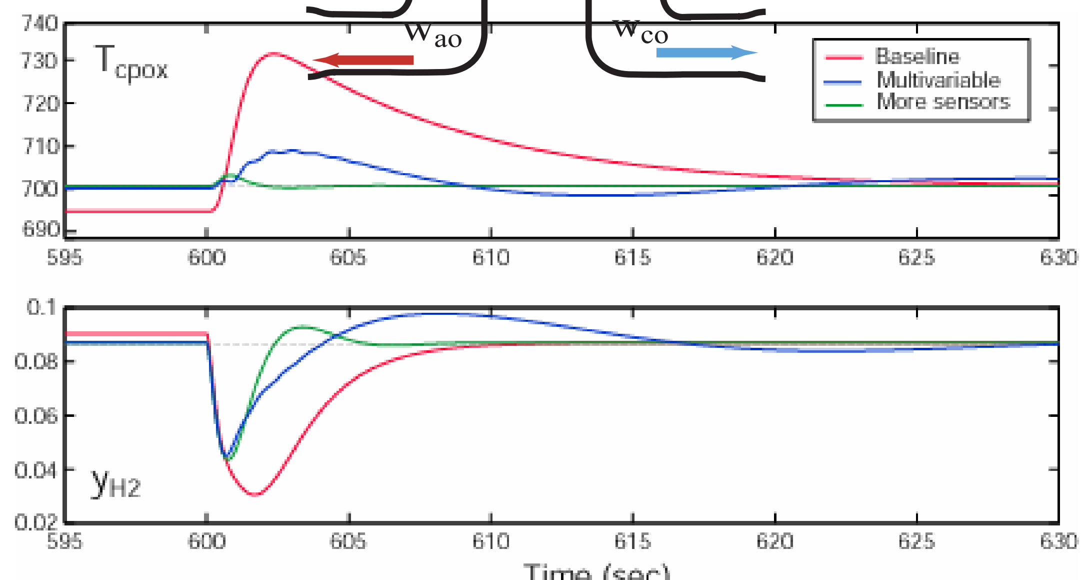
- Output Hydrogen concentration
- Near-zero CO concentration
- Optimum reactor temperatures

Fuel	Energy Efficiency* (%)	
	POX	SR
Methanol	Data n/a	83.2
Natural Gas	77.5	85.5
Gasoline	55.8	81.2
Diesel	55.7	81.2
Jet fuel	54.9	81.2

* Source: Brown, *Journal of Hydrogen Energy*, (26)4 , 2001

Detailed Modeling and Control of FC+FP





Control of
- Catalyst Temperature
- Hydrogen Starvation

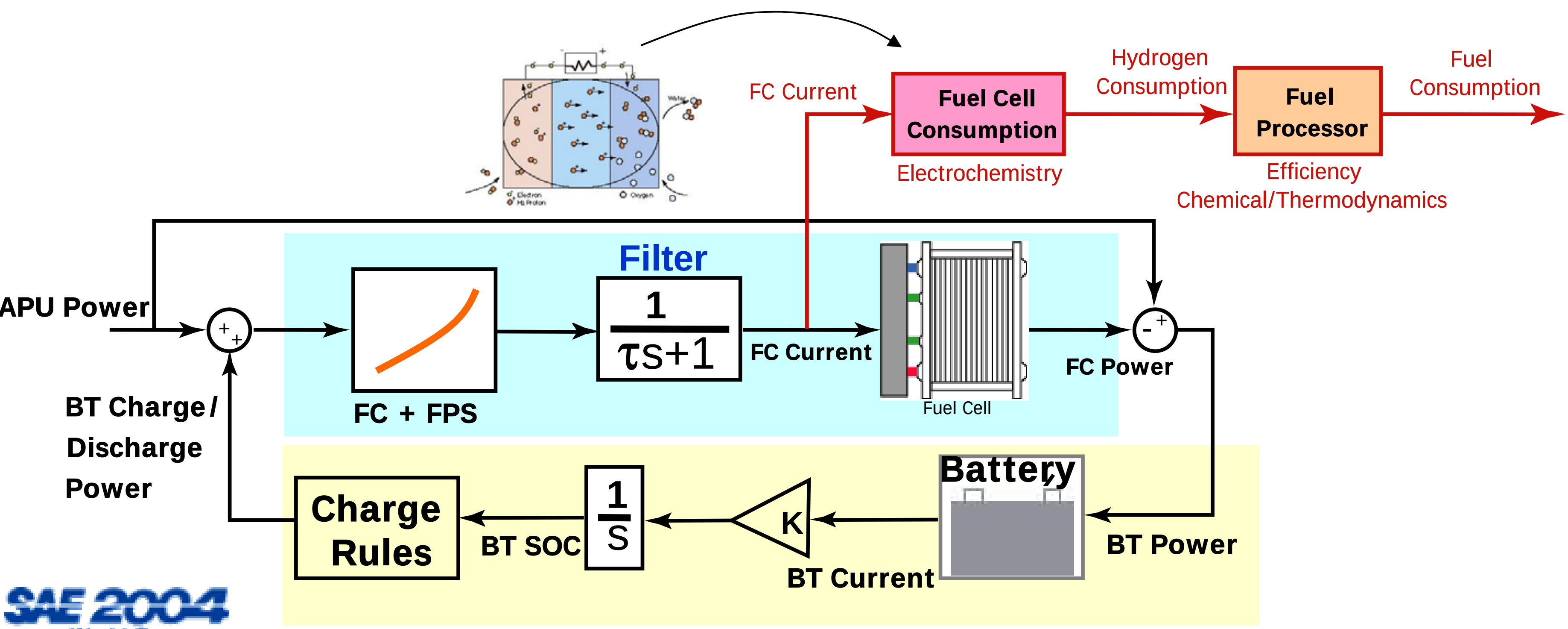
- ➢ Efficiency
- ➢ Responsiveness
- ➢ Life

FC APU Simplified Model

Given the electric loads, the APU model calculates the fuel consumption

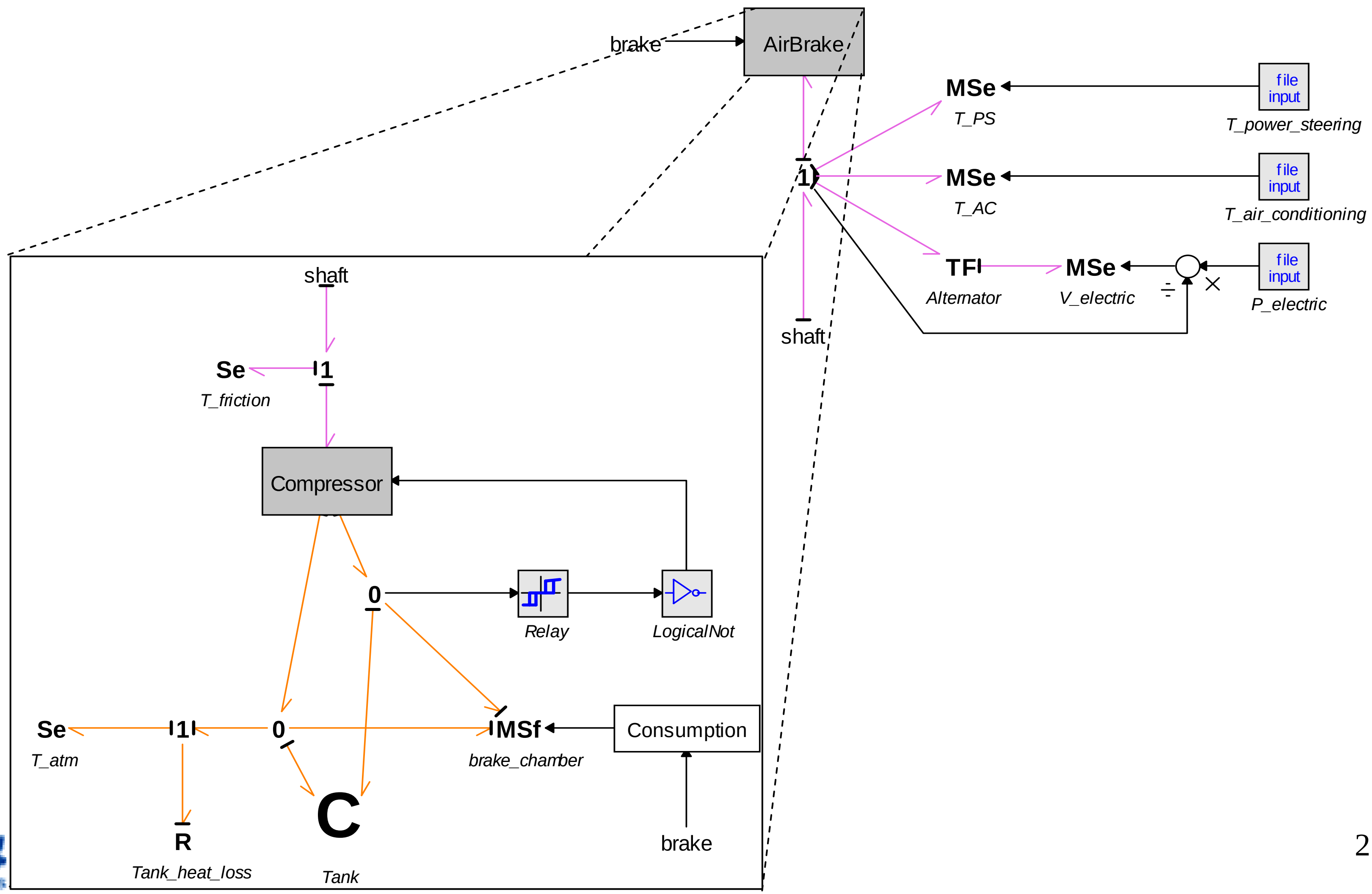
Existing FMTV battery packs (four 6TMF 12V batteries) will buffer the FC APU system from *transient loads*.

Due to significant number of transients in APU applications, battery charge/ discharge (efficiency) model needs to be included.



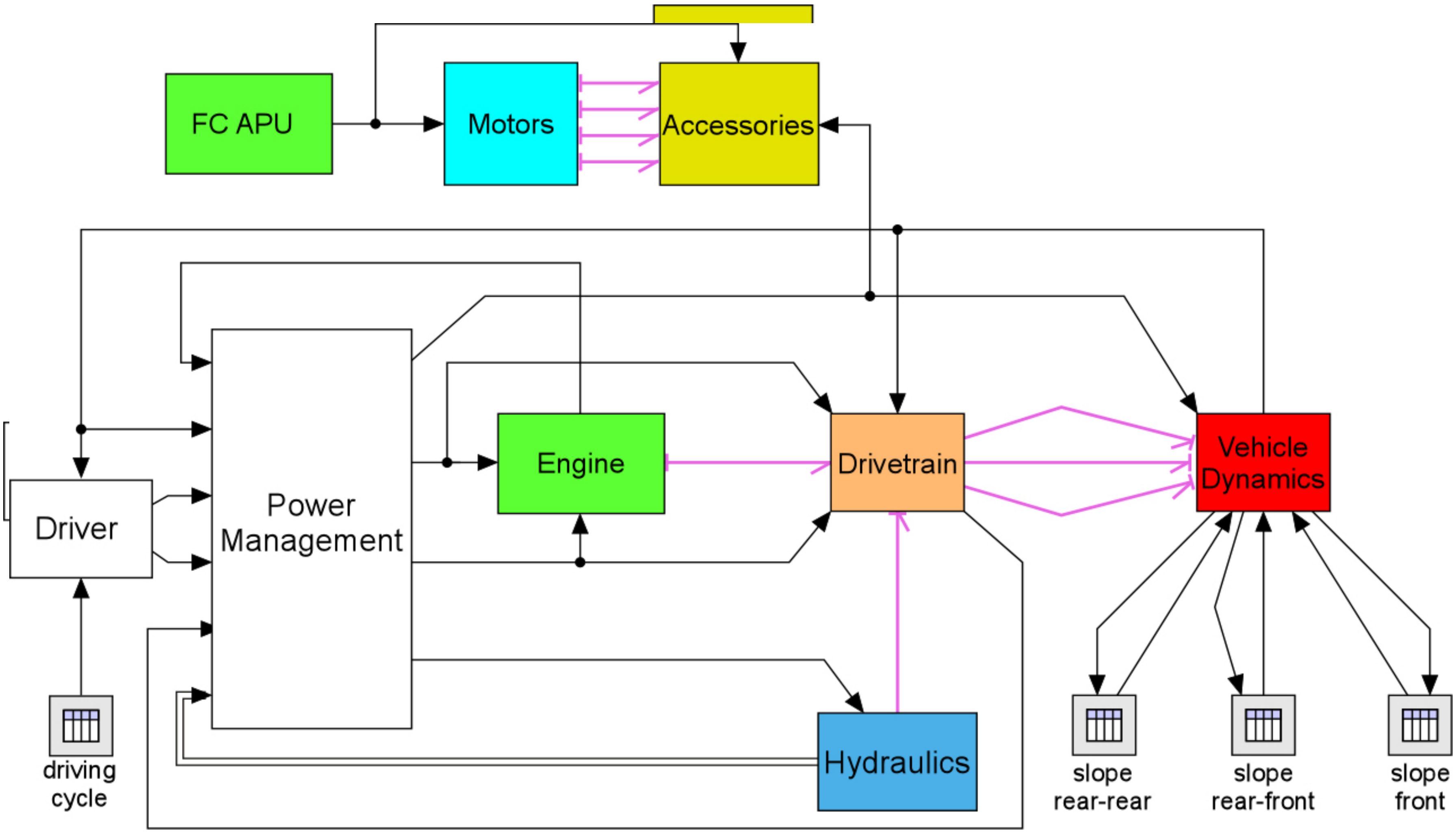
Accessories

Developed in 20SIM Modeling and Simulation Environment



Vehicle Engine SIMulation - VESIM

Developed in 20SIM Modeling and Simulation Environment



Results

Simulation Results (current technology)

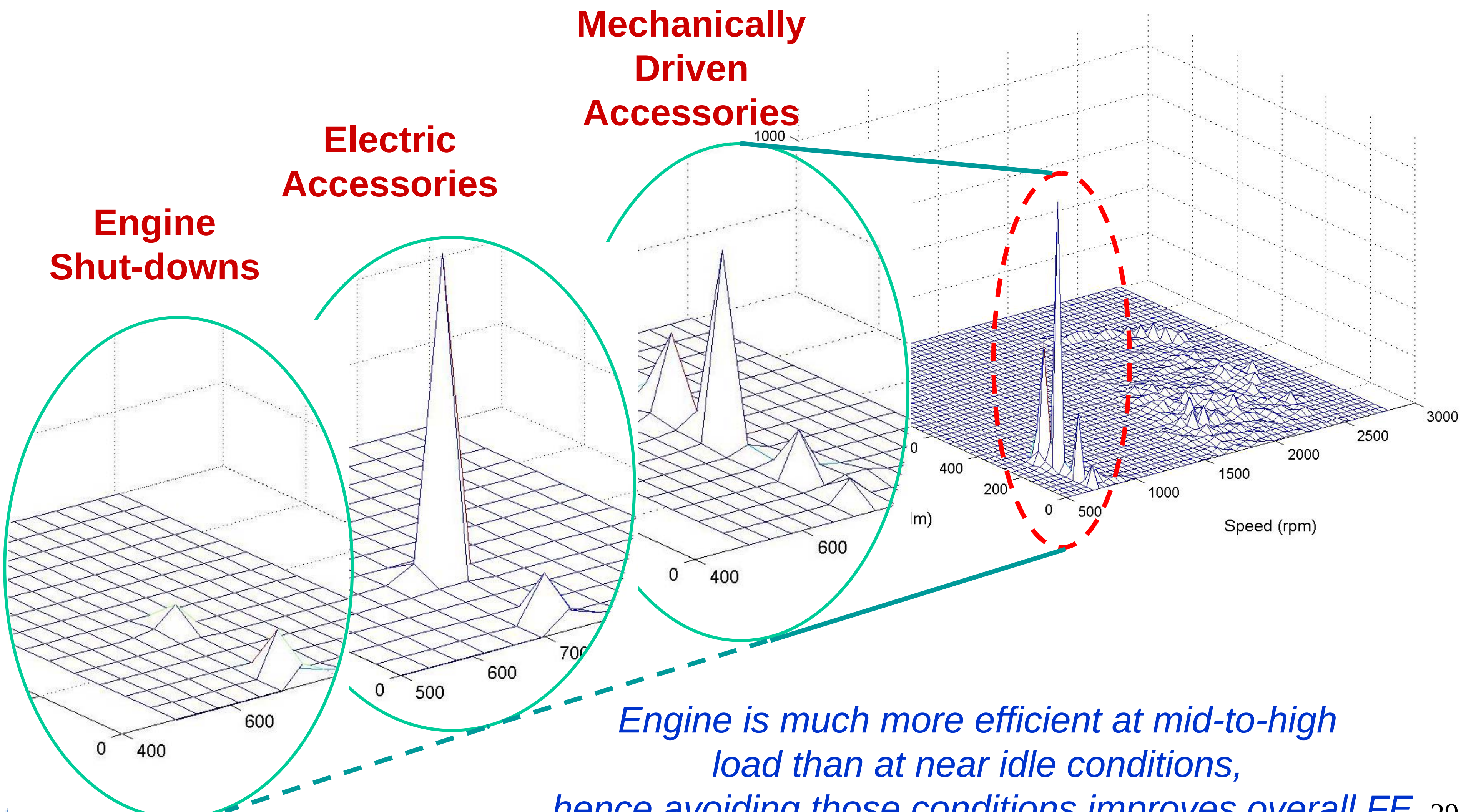
Silent watch – 10 hours

Energy Source	Fuel consumed [gallon]	Improvement [%]
Diesel engine (@ idle speed)	8.6	-
Fuel Cell APU	1.5	575 %

Driving

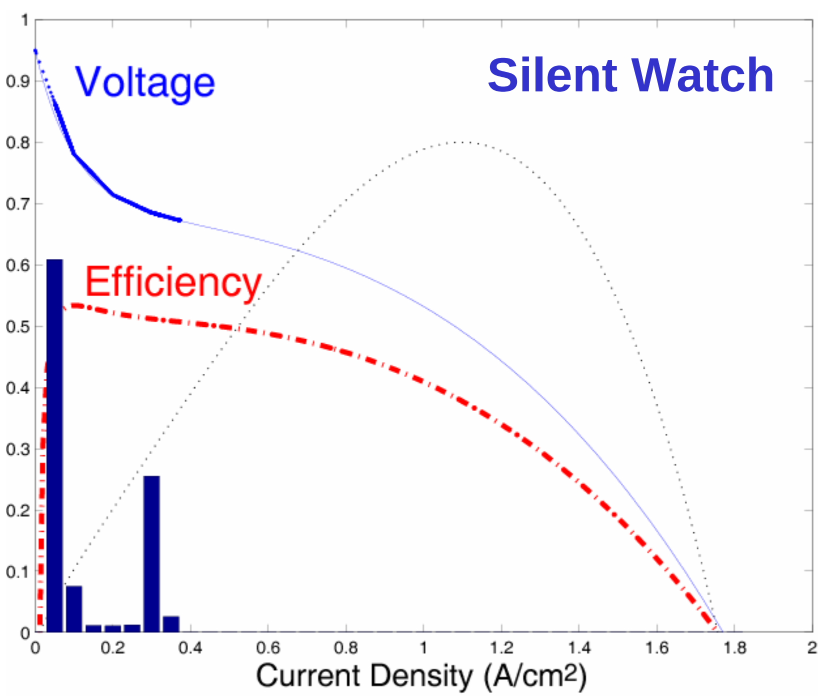
Energy Source	Propulsion Fuel Consumption [gallon]	Accessory Fuel Consumption [gallon]	Overall Fuel Economy [mpg]	Improvement [%]
Diesel engine only	2.28	0.369	6.20	-
Engine + Fuel Cell APU	2.22	0.306	6.56	5.8 %
Engine + Fuel Cell APU (Engine shutdown)	2.14	0.306	6.77	9.2 %
Engine + Fuel Cell APU (Engine shutdown & 95% Engine scaling)	2.11	0.306	6.84	10.6 %

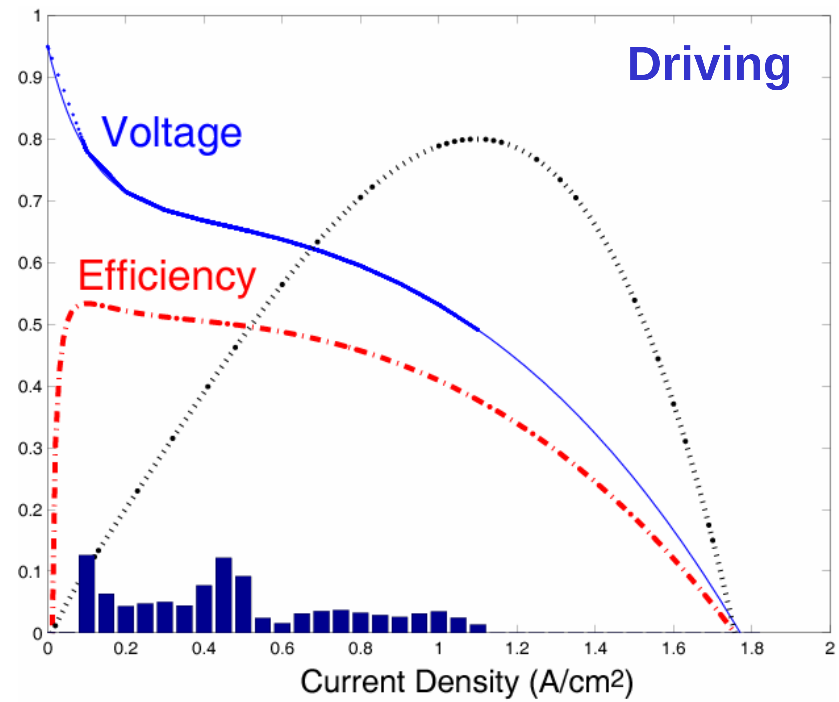
Engine Visitation Points



Engine is much more efficient at mid-to-high load than at near idle conditions, hence avoiding those conditions improves overall FE

Fuel Cell APU Performance





	Fuel Consumption [gallon]	FC Eff. (%)	FP Eff. (%)	Total Eff. (%)
10 Hr Silent Watch	**1.46**	**50**	**55**	**28**
Driving	**0.31**	**47**	**55**	**26**

Tactical Truck Work Day

10 hours of driving

10 hours silent watch

4 hours of rest

Energy Source	Fuel consumed [gallon]	Improvement [%]
Diesel engine only	51.9	-
Engine + Fuel Cell APU Engine shutdown	41.5	20.1%

Save one tank of fuel in 6 days of operation or extend the range by 70 miles

Conclusions – FC APU

- Insertion of FC APU significantly increases silent watch fuel efficiency
- Limited powertrain electrification provides moderate improvement of driving fuel economy
- Combined silent-watch and driving fuel savings reduce fuel supply requirements by 20%

Thank you!

Q&A

Advanced Technology Fuel Cell

Advanced Technology based on Projections and Research Prototypes
- **New material for CO tolerant electrode and membrane**
- **Thermal integration with combined control and optimization**

10kW peak
Size reduction: 65 cells→ 38 cells
APU efficiency: 26% →36 %