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# First Hydrogen Fuel Cell Demonstrations for Bundeswehr Land Forces

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# Outline

- Motivation – Expected benefits of fuel cells for military applications
- Hydrogen as fuel in the military environment
- The selected demonstration application
  - Autonomous land vehicle Mustang MK1
  - 2 kW<sub>el</sub> tactical generator
- The realised fuel cell systems
  - Mustang fuel cell range extender
  - Fuel cell based tactical generator
- Evaluation of the result
- Conclusions and outlook

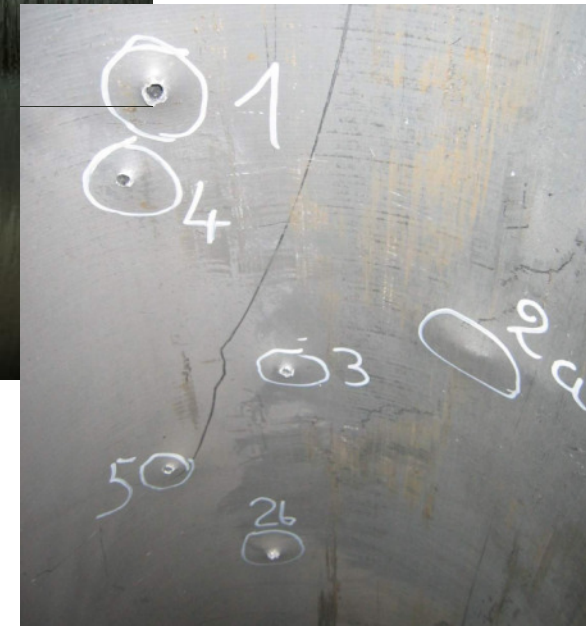
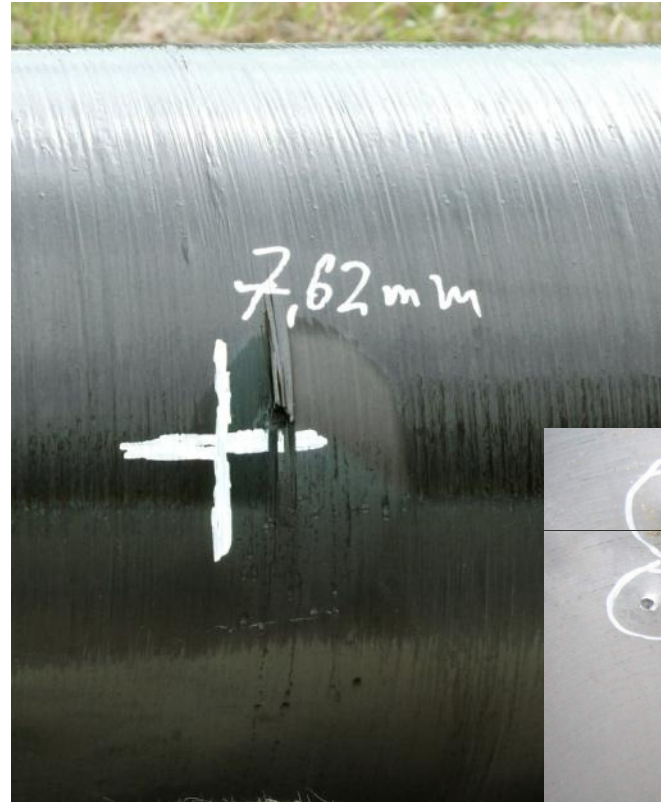
# Motivation – Expected benefits of using fuel cells

- In the power range investigated here fuel cells will mainly compete against small combustion engines.
- Therefore expectations on expected benefits will consider the current state-of-the art of such engines
- Major benefits are expected with respect to the signature of the devices due to the “cold combustion” of hydrogen
  - Strong reduction in noise emission
  - Strong reduction in emission of exhausts
  - Reduction of the IR emission
- Additional expected benefits
  - Less weight because of less mechanical parts

# Hydrogen as fuel in the military context

- Major obstacles in introducing hydrogen into armed forces are concerns about:
  - The safety of in theatre hydrogen handling
  - The security of in theatre hydrogen supply
- First tests on the safety of pressurised hydrogen tanks at the WTD 91 in Meppen revealed that these tanks are fairly safe if hit by bullets up to calibre 12.7 mm.
- Even after being hit by 40 mm hollow charge the tank and in particular the contents were left as a single piece.

# Hydrogen as fuel in the military context



*Test with 7.2 mm ammunition  
Distance 40 m to 500 m, angle 45 °*

*The bullet penetrates the hit wall of the container.  
However, depending on the distance it does not  
penetrate the rear wall. Hydrogen is blown out.*

# Hydrogen as fuel in the military context



*Test with 12.7 mm ammunition  
distance 40 m*

*Hydrogen is ignited on impact and leaves the  
container within a few seconds with a large flame.  
The container is damaged in the area of the impact  
but not much elsewhere*

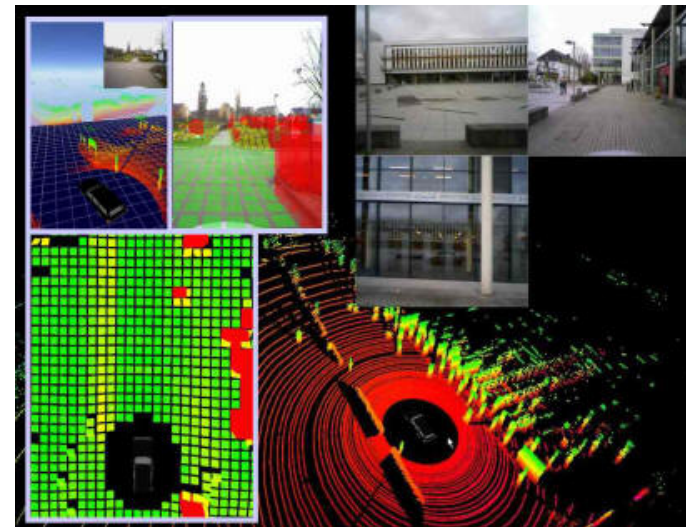


# Hydrogen as fuel in the military context

- The security of supply is however still a challenge
- One point is the lower volumetric energy density of hydrogen compared to diesel
  - This will increase the amount of fuel which is needed to be transported
  - However, the effect can be compensated at least partially by the high conversion efficiency of the fuel cell
- The more important point is the lack of standardisation of hydrogen container inlets and outlets, which renders it difficult to establish and structured logistic supply chain

# Applications – Autonomous Land Vehicles ALV

- The ALV Mustang MK1 which is currently developed at the WTD 51 is intended for the reconnaissance mission.
- It is equipped with four hub motors of 0.55 kW, a 3D laser scanner, a camera and several other sensors
- In total the electric payload sums up to ca. 3 kW peak
- In its original configuration a 2 kW diesel engine was used to enhance the operation range by recharging the internal lead acid batteries
- In the project the engine was to be replaced by a 2 kW fuel cell systems



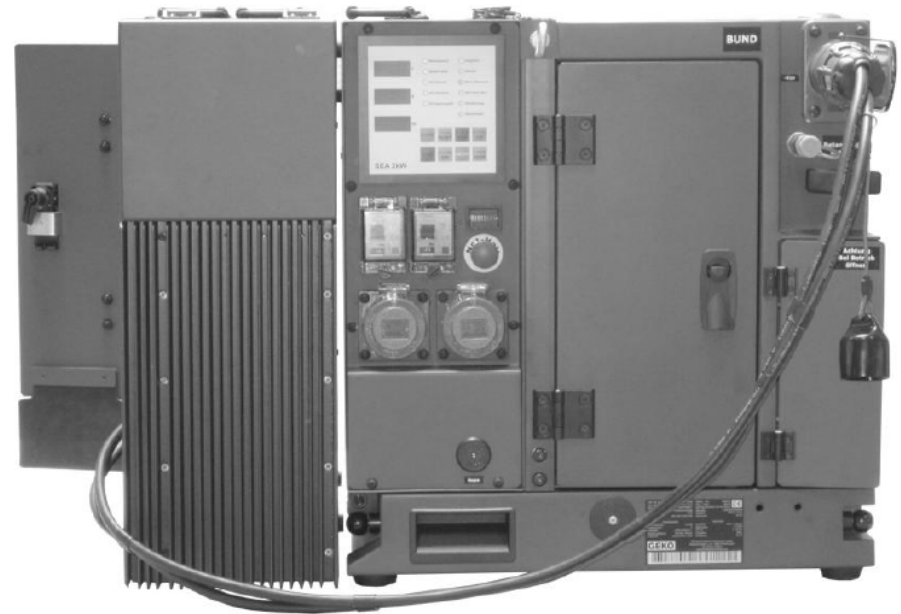
*Picture of the Mustang MK1 ALV (upper) and the sensor data created (lower)*

# Applications – Autonomous Land Vehicles ALV

- The following benefits were expected
  - Significant reduction of noise and vibration
  - Avoidance of negative effect of particular matter emissions on the sensor capabilities of the vehicles
- The vehicle was also operated with four instead of two batteries but without the motor to avoid the motors noise and pollutant emissions.
- In comparison to this configuration it was further expected
  - That the weight of the system can be reduced
  - That the endurance can be increased

# Applications – 2 kW Tactical Generator

- Tactical generators are used to supply smaller forward operating squads with electrical energy
- The generator should be portable by two soldiers limiting its weight to 65 kg
- In accordance with NATO's single fuel policy former petrol generators have been replaced by a 2 kW diesel generator.
- The weight of the generator could only be kept at the limit of 65 kg by separating the starter battery module
- Beside the heavy weight of the system also its strong emission of noise is undesired.



*Power generator SEA 2kW "Gekko" currently in service at the Bundeswehr, with installed starter battery module on the left side*

# Applications – 2 kW Tactical Generator

- The expected major benefits for this application are
  - Reduction of noise and pollutant emissions
  - Reduction of the weight of the system
  - Reduction of the IR signature

# The realised fuel cell system: General Considerations

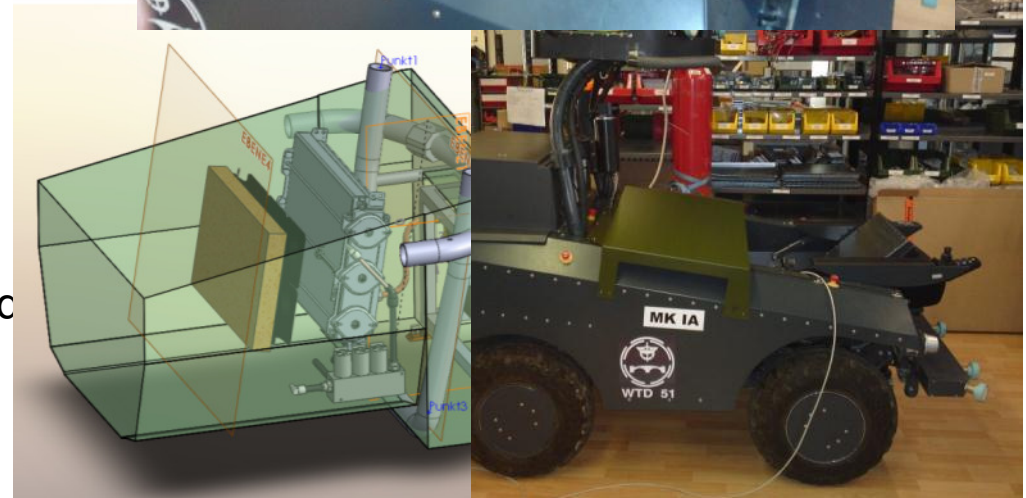
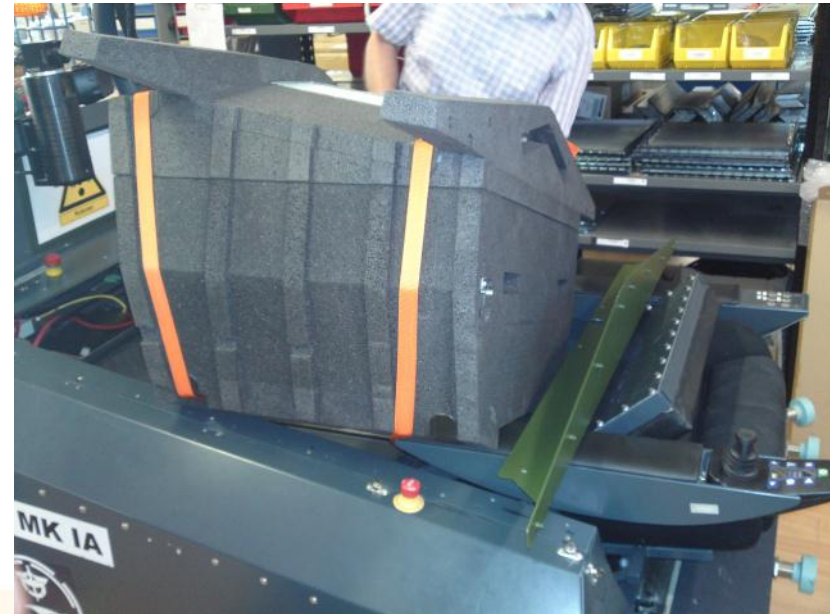
- A common request to both systems is a low weight of the system
- Likewise, a high efficiency is required in both cases
- From this main requirements it was concluded that an air-cooled system with open cathodes should be better suited than a liquid cooled system because with closed cathodes
  - Additional weight for coolant, pumps and plumbing is avoided
  - The parasitic load for blowers should be lower than that of air pumps or compressors
- The disadvantage is however, that due to the high air flows it was expected that the system might not be as silent as desired
- FutureE was selected as provider of the system.

# The realised fuel cell system: General Considerations

- Both systems use the same stack as both require a rated electrical power of 2 kW
- The stack which is also used in other FutureE fuel cell systems is Ballard's air cooled FCgen 1020 ACS
- For both systems a single large blower is used for air supply and cooling in order to reduce the noise of the blower
- The stack is mounted in a polymer foam case
- This has several advantages
  - The foam case is lighter than other possible housing materials
  - Additional weight is saved by using the foam case structure to guide the air
  - Finally the foam case also serves as thermal isolation as well as shock protection.

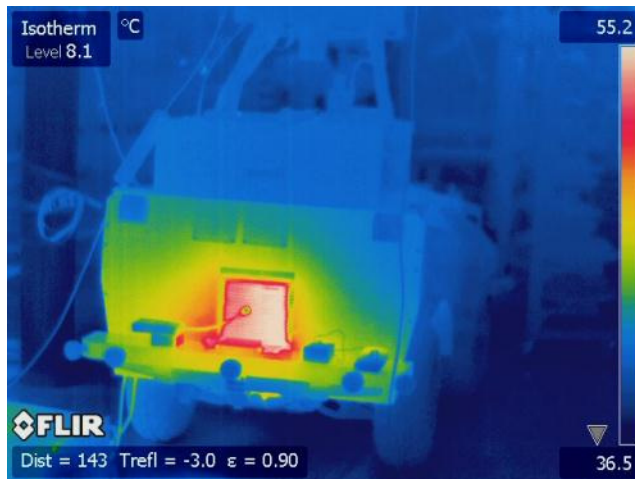
# The realised fuel cell system: Mustang MK 1

- The fuel cell system was integrated behind the driver seat of the vehicle.
- Tanks will be placed on the hood of the Fuel cell system cover
- The system is used as a range extender:
  - when started it charges the batteries till the maximum battery voltage is reached;
  - after that it switches to stand-by;
  - in stand-by it senses the battery voltage and turns the fuel cell on again if a lower limit is passed.
- To allow for stand-by at temperatures below 0 °C an electrical heater has been integrated to avoid freezing.



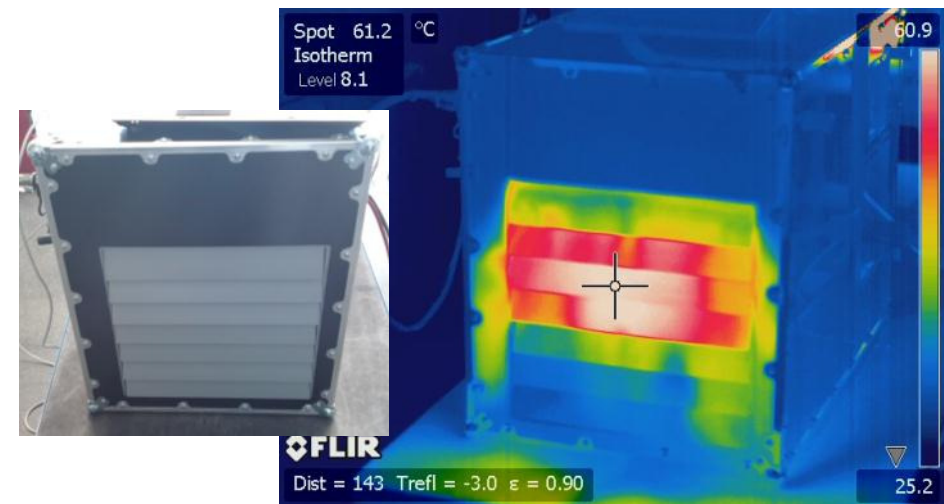
# The realised fuel cell system: Mustang MK 1

- To avoid condensation in the vehicles electronic system, the humid cathode exhaust is gathered in a channel and guided to the rear end of the vehicle.
- For this point the highest temperature of the system is expected.
- Also purged hydrogen is leaving here
- Both temperature values and hydrogen concentrations are uncritical



# The realised fuel cell system: Tactical generator

- For the tactical generator the foam case was surrounded by a external case of carbon reinforced plastics.
- The case protects the fuel cell against shocks and bumps
- It also ensure protection against dust and splash water according to IP 65
- A lithium battery was integrated as the operation must be possible without external power source.
- Foldaway handles allow for easy transportation by two soldiers
- The front panel allows for connection of two devices with 230 VAC power requirement and two devices with 24-28 VDC requirement
- The electrical protection fulfils the legal requirements



# Evaluation of the results

- The systems were realised to demonstrate certain benefits of fuel cell systems.
- This was accomplished in some points as depicted in the table below

Expected benefit	Result Mustang	Results Tactical Generator
Reduction of noise	Achieved at low loads	Achieved
Reduction of emissions	Achieved	Achieved
Increased endurance	to be tested	not aspired
Reduction of IR signature	Achieved	To be tested
Reduction of weight	Not accomplished if hydrogen tanks are considered	Nearly accomplished

# Evaluation of the results

- The comparison of the expectations to the results reveals two critical issues
- First noise from the blower is especially for high loads still somewhat high.
  - However this had been almost expected because of the selected system.
  - Furthermore, noise optimisation measures compared to these first prototypes are clearly possible.
- The other point is that the weight of the systems is rather high
  - Mustang systems about 40 kg without hydrogen tanks, target have been 35 kg
  - Tactical generator close to 50 kg without tanks target has been 40 kg
- However, both systems are first prototypes.  
An evaluated list of possible weight reduction options shows a clear path to fulfil the target values within further development efforts.

# Evaluation of the results

- The reasons for the high weight are different for the two systems
- For the tactical generator it is mainly the electrical system which is contributing
  - High energy lithium ion battery to allow for immediate start-up
  - High quality DC-AC converter
  - Layout of the system as Isol e Terre System with an addition earth leak monitor for supply security reasons
- The weight of the Mustang system is however mainly due to the stack, which is originally thought for stationary applications.

# Conclusions and Outlook

- Two fuel cell systems for military applications in the 2 kW class have been realised using hydrogen PEMFC
- The purpose to demonstrate certain benefits of this technology was accomplished in many points.
- Weight is still an issue, however, a clear path for weight reduction could be identified for a next development effort.
- Further developments may be needed to further comply with standard environmental requirements as given in the NATO AECTP standards.

# Thank You for Your attention!

## Questions?

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