Roadmap of sustainability in Automated Horizontal Transport

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General aspects influencing energy consumption that determines emissions

- Weight and Payload of Vehicle
- Automation can control driving behavior (acceleration / deceleration) which is a core parameter influencing consumption
- Component selection (Low noise and low energy consumption i.e. hydraulic pump)
- Automation provides better energy saving designs and processes (Sleep modes)
- Good Management System provides optimal selection of Vehicle to perform the Task
- Automation can help balancing the vehicles acceleration vs. the required terminal performance
- ……

AGV History (16 Years Ago)
Customer Demands: Improve Energy Efficiency, Emissions, Performance, Cost

The first diesel-hydraulic AGVs are put into commercial service

1993

2006

First diesel-electrically driven AGVs launched

The launch of the diesel-electric Lift AGV results in optimised processes

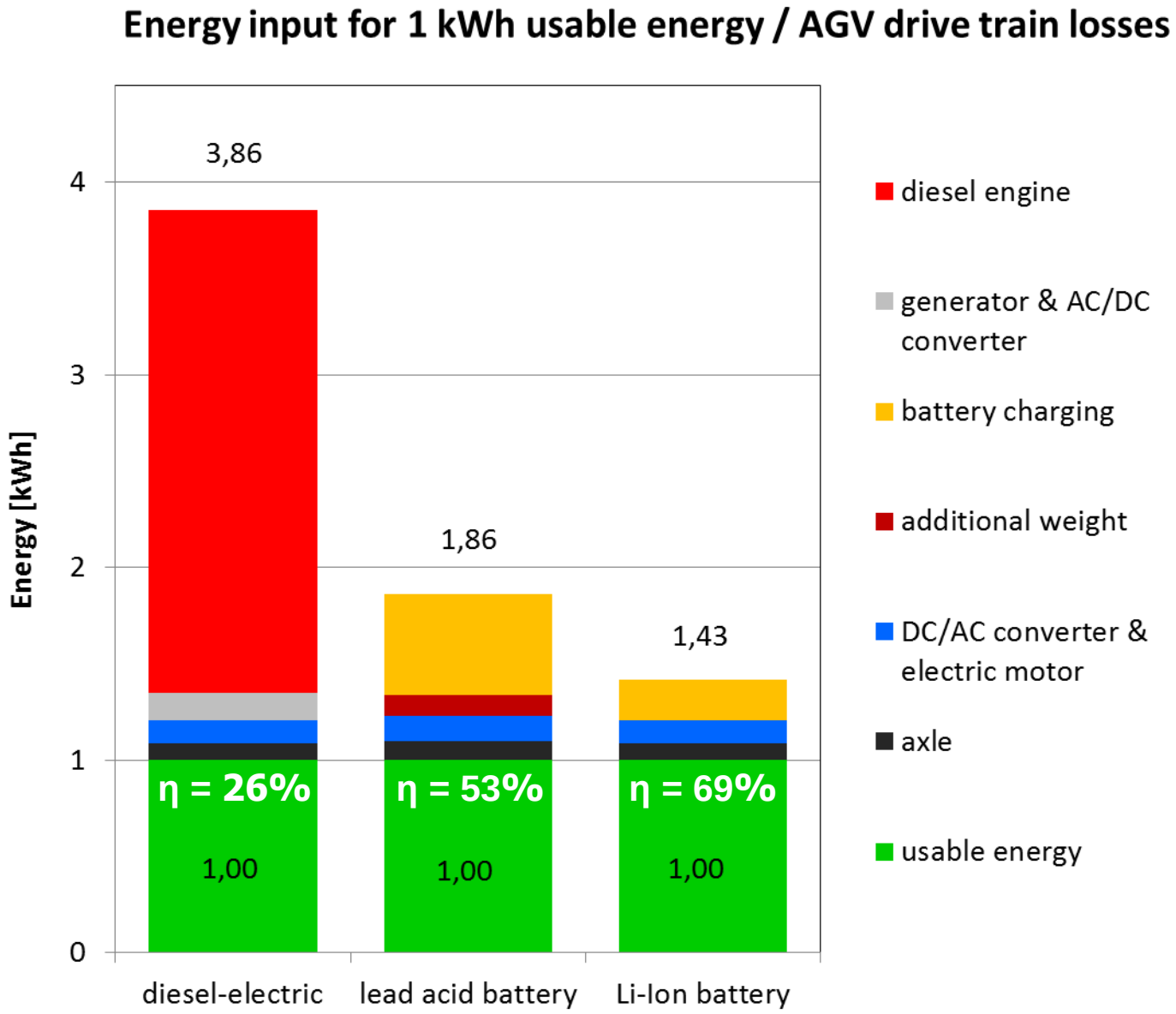
2007

- Optimized Diesel-Electric Drive
- Hybrid Drive
- Fully-Electric Drive
- Energy Storage System
- Charging Strategy

?

Energy Efficiency

1. Battery-electric drives give by far the best energy efficiency compared with internal combustion engines, hybrid drives or fuel cell technology
2. Energy efficiency will be further optimized using Li-Ion batteries instead of lead acid batteries
3. Local zero-emission technology
4. The absolute carbon footprint depends on electric energy generating technology



CO2 Emission Case: Automated Guided Vehicle (AGV)

Diesel-electric

Operation: 7.5 liters diesel per hour

diesel fuel inclusive fabrication and transportation
3.14 kg CO_2/liter

23.6 kg CO_2 per operating hour

Battery-electric

Operation: 13.2 kWh electricity per hour

charging (η_{tot} = 85%)

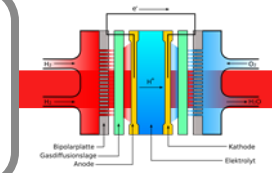
Electrical grid: 15.5 kWh electricity per hour

global energy mix
0.453 kg CO_2/kWh

7.0 kg CO_2 per operating hour

Fuel cell

Operation: 13.2 kWh electricity per hour



H_2 production, compression, transport, fuel cell (η_{tot} = 36%)

Electrical grid: 36.6 kWh electricity per hour

global energy mix
0.453 kg CO_2/kWh

16.6 kg CO_2 per operating hour

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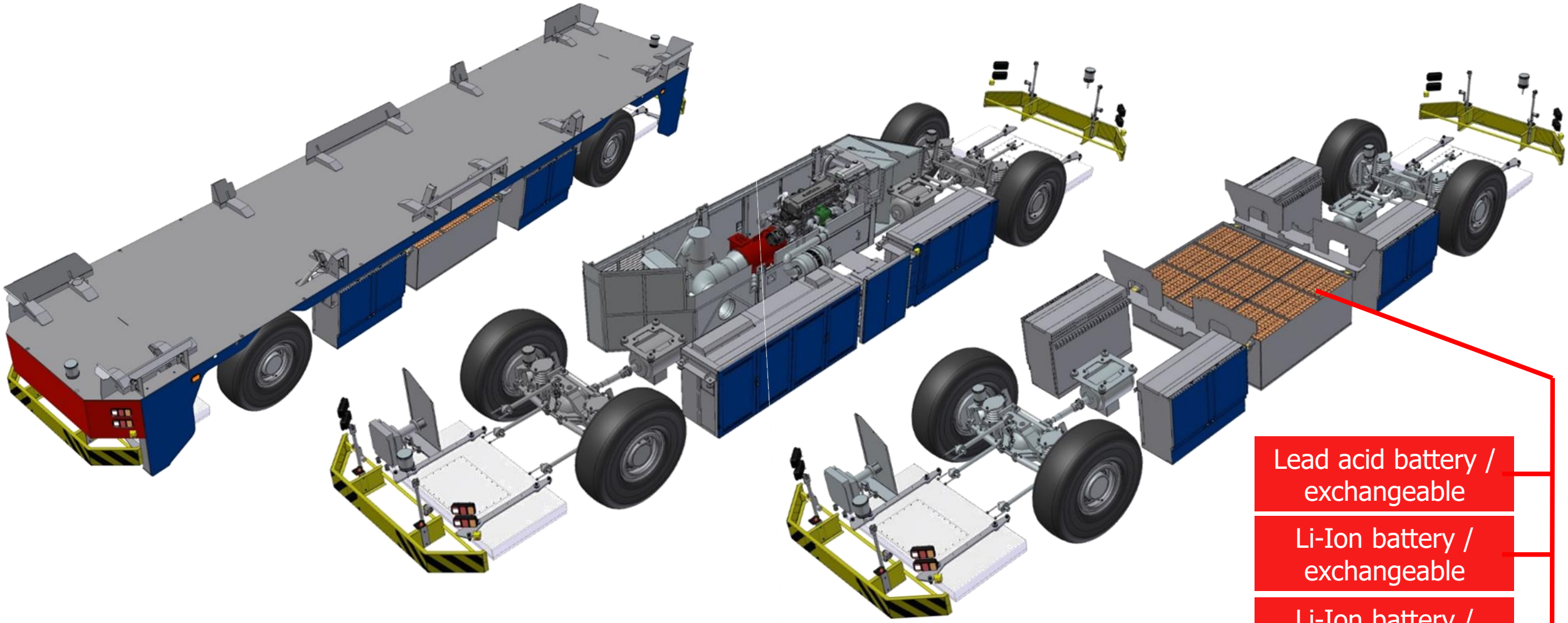
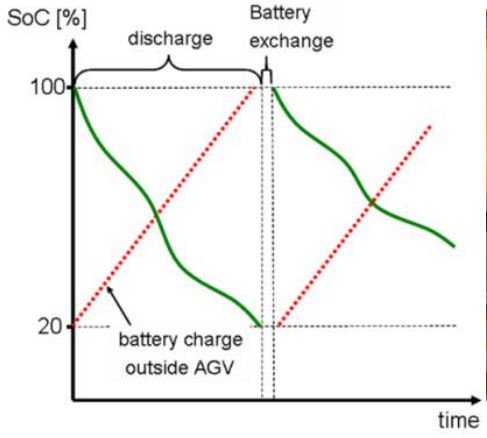
AGV Modular Design Approach

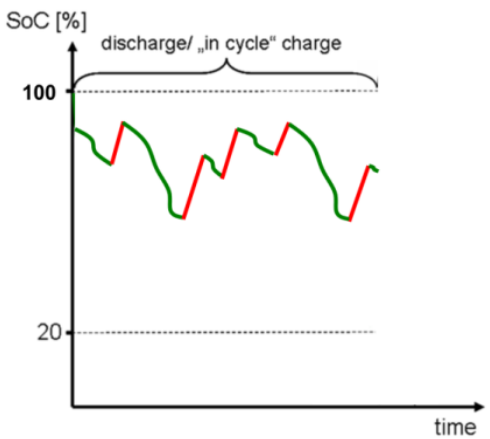


- Lead acid battery / exchangeable
- Li-Ion battery / exchangeable
- Li-Ion battery / fixed Installation
- Spacewise others possible i.e. Fuel Cell / Hydrogen

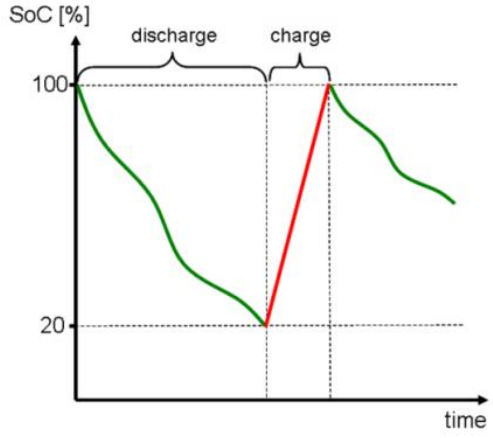
Battery Charging strategies (1)



Lead-Acid AGV



Bus



Li-Ion-AGV

Battery exchange

- Discharged battery is exchanged by a fully charged one (manual or automated)
- Batteries are charged in a separate charging station
- Long charging times do not impact operation

- **Suitable for systems that need long, uninterrupted operations**

Opportunity charging

- Charging small amounts of energy
- Chargers have to be installed at positions where vehicles stop during normal process
- High number of battery chargers is required, low utilization of chargers
- Very high charging power required
- Requires planned, repetitive operating cycles

- **Suitable for systems with "fixed" schedules and planned short stops**

Dedicated quick charging

- Vehicle is taken out of normal work cycle for battery charging
- Low number of chargers, high utilization
- Depending on individual requirements 5% … 10% additional vehicles
- Short charging times required

- **Suitable for systems that need long, uninterrupted operations**

BATTERY CHARGING STRATEGIES (2)

Strategy depends on customer demands:

1. Throughput (TEU per year)
2. Terminal performance
3. Shift operation
4. Fleet size
5. Redundancy
6. Area demand
7. Electrical infrastructure
8. In case Li-Ion, Battery Cell Type
9. Battery lifetime and battery cost developments
10. TCO calculation

	Lead acid battery	Li-ion battery
Battery exchange	✓	✓
Opportunity charging	✗	✓
Dedicated quick charging	✗	✓

Automated Charging System (ACS) for Li-Ion Batteries

- 18 ACS delivered and in operation since 2016 with hardly no issues.
- ACS will arrive at site **pre-tested** and fully operational in 20feet standard Container.
- Erection and commissioning within 14 days.
- Imbedded redundancy possible
- Same Technology for Battery Straddle Carrier
- Usage of Li-Ion Battery in Flexible Power Grid successfully tested

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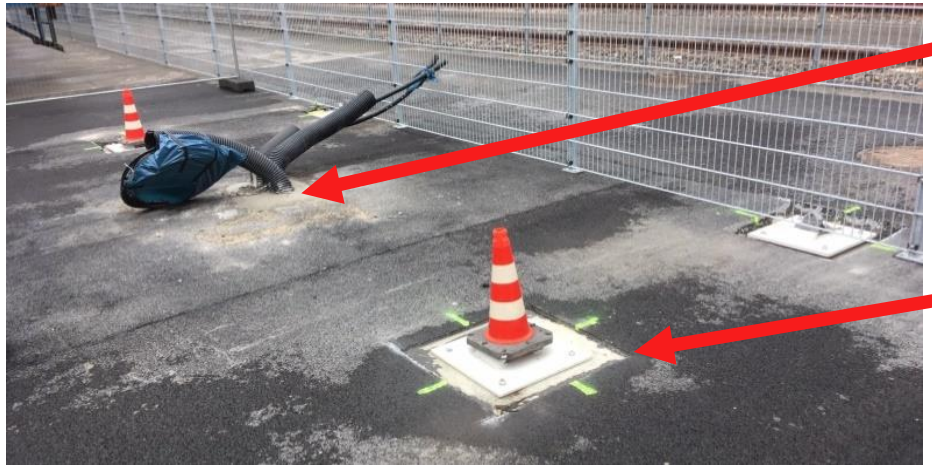
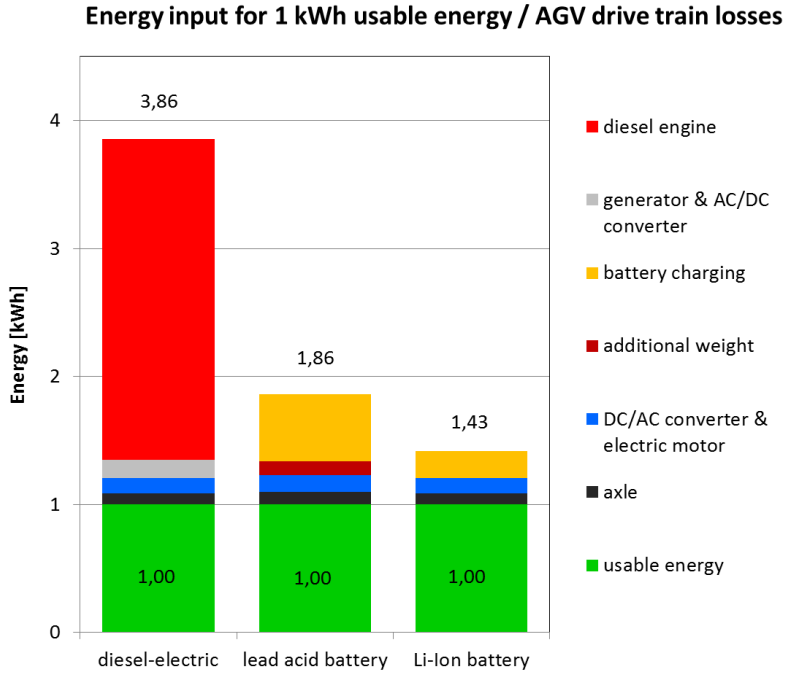


Summary for Li-Ion Technology

- +10% Energy savings compared to Lead Acid
- No Battery maintenance required
- Total CAPEX substantially lower (civil & charging technology)
- Mixed operation with Diesel-Hydraulic, Diesel Electric, Lead Acid and Li-Ion AGVs successfully conducted over years.
- Existing Vehicles can be retrofitted with acceptable effort
- 2 Battery Suppliers available



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Thank’s for listening.