HYSTER-YALE GROUP

In Partnership With

WAVE Wireless Advanced Vehicle Electrification

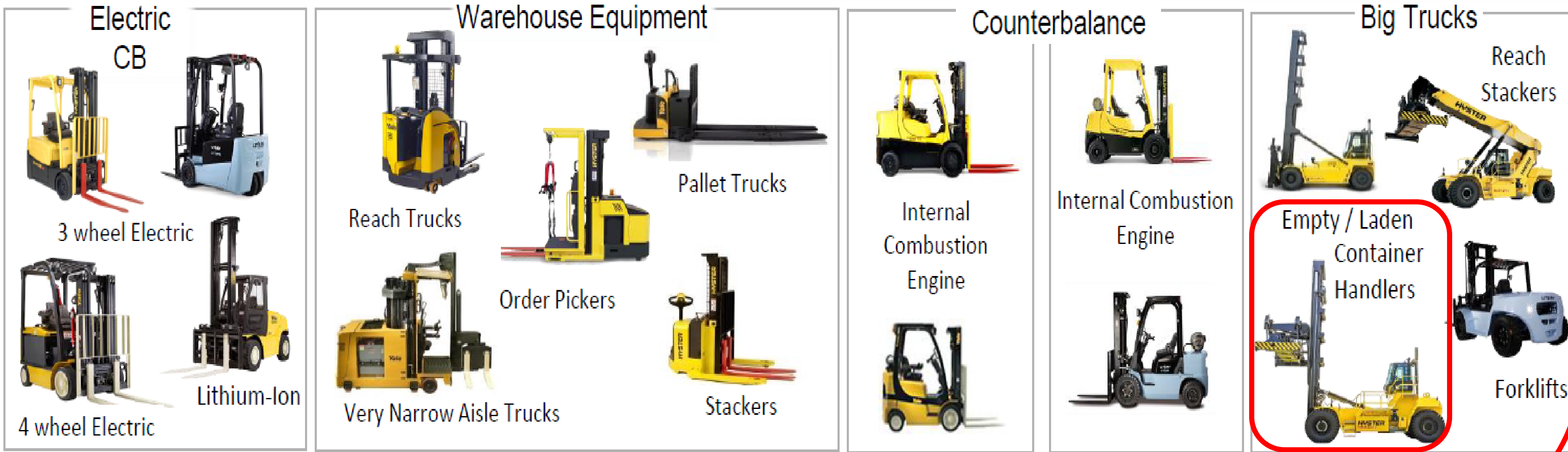
NUVERA® Making hydrogen make sense.

Top Loader Electrification Proposal for POLA Operations

Laurence Dunn Chief Engineer II 2018

Planned Fuel Cell Application

CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5
Electric Counterbalanced Rider Trucks	Electric Narrow Aisle Trucks	Electric Hand Trucks	Internal Combustion Engine (cushion tire)	Internal Combustion Engine (pneumatic tire)
1.0T to 5.5T	1.5T to 6.0T	1.5T to 8.0T	1.0T to 7.0T	1.0T to 52.0T



Over 280 different truck models available

The Proposed Vehicle Conversion

Hyster' s prototype platform
Zero Emissions solution for Laden Container Handlers based on the **H1150HD CH (H52XM-16CH)**

Key characteristics:

- Load Capacity: 52 tons
- Vehicle weight: ~80 tons
- Lift height: 6 x 3 meter high containers
- 800 liter Diesel Fuel tank = 37 hours run time (assumes 40% efficiency)

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Zero Emissions Benefits

- Environmental Improvements
  - Eliminate Fossil Fuel Emissions at all CA locations where ICE products are used
  - Powertrain Noise Elimination from Population areas
- Carbon Reduction per vehicle = 2.63 kg/l x liters used
  - the average fuel consumption of a top loader is around 16 L/hour => 42.7 kg/hour
  - 3000 h average per year => 128000 kg.
- Reduce the Cost of Operations
  - Lower Energy Costs
    - Target is > 35% Reduction
    - $0.65/ kWh for Diesel vs $0.15/ kWh for Electricity.
      (Note that Hydrogen is currently $1.97/kWh)
    - Where possible use Energy Storage during Off Peak Hours
  - Reduced Maintenance
    - Electric Powertrain vs ICE Powertrain
    - Zero Maintenance Energy Storage – Li-Ion Batteries
    - Wireless charging to eliminate Cable and Connector Repair
  - Higher Productivity
    - Less Vehicle Downtime due to Maintenance
    - Wireless Charging reduces refueling time by eliminating wired charger connection times – typically 3-5 minutes per charge x 4 times per day x 3 shifts = 36 minutes / day/ truck Multiply that by the number of trucks in a fleet x the hourly rate of an operator

The Onboard Energy Storage Challenge

Current Diesel Storage vs the equivalent Electric:

- *800 liters of Diesel (= 800 x 9.7kW/l) = 7760 kWh*
- *7760 kWh battery pack*
  *Lead Acid =***114 m^3**, **291 metric tons**.
  *Li-Ion =***57 m^3** , **97 metric tons**.

Equivalent Hydrogen :

- *800 liters of Diesel (= 800 x 33.3) = 233Kg H2*
- = **5.8 m^3** @ 700bar.

Usable Diesel Storage vs the equivalent Electric:

- *800 liters of Diesel (= 800 x 9.7kWh/l) = 7760 kWh x 40% = 3104 kWh battery pack = to about 37 hours of runtime*
- *Lead Acid Battery =* ***46*** **m^3**, **116.4 metric tons**.
- *Li-Ion Battery=***22.8 m^3**, **38.8 metric tons**.

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The Onboard Energy Storage Challenge

- **Battery Sizing for Typical usage:**
  - *20 Liters Diesel/ hour (= 20 x 4.2kWh/l) = 84 kWh x 8 hours = 672 kWh battery pack*
  - *Only 80% of the battery energy is usable so capacity needs to be increased by another 20% = 800kWh*
  - *Required Li-Ion Battery=* **2.2 m^3**, **4.2 metric tons**.
- **Battery Sizing for the available space:**
  - *Use the Highest Energy Density Li-Ion Chemistry = NMC*
  - *Operating Voltage = 700 to 800 Volts*
  - *Available Space=* **1.1 m^3**, **2.1 metric tons** = 400 kWh
- **H2 Storage for the available space:**
  - *20 Kg @350 bar with Battery reduced to 125kWh*

WHAT IS NEEDED: Application specific truck configurations + Intelligent Design.
- Optimized Sizing of batteries and hydrogen system linked with Smart charging/Refill strategy
- Smart energy recovery for maximum efficiency

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Operational challenge - Battery only

Battery pack calculation model

Inputs:

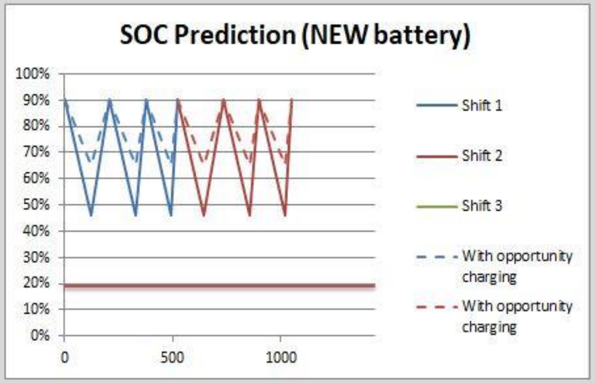
Average energy consumption	84	[kW]	Average energy consumption based on continuous driving according to prescribed pattern, calculated in virtual model
Opportunity charging	370	[kW]	Max charge rate during short stops on wireless charging system (max. 15 min.)
Normal charging	370	[kW]	Long term charging rate for overnight / lunch break charging
Annual operating hours	4500	[hr]	
Battery config	381.5	[kWh]	Based on 9T battery configuration (1 pack is 28 kWh)
Cycles to 80% capacity (EOL)	5000		Based on 9T NMC type batteries
C-rate	1		Rated C-rate for number of cycles

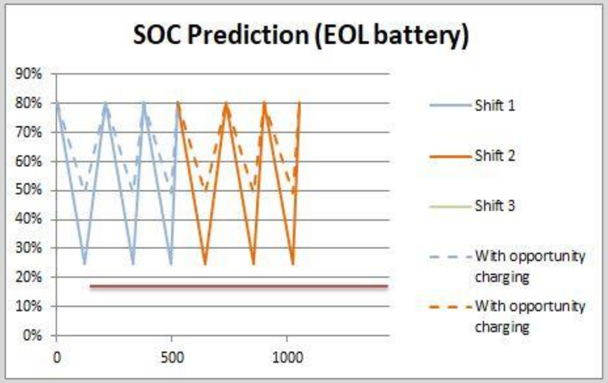
Capacity when New	Max charge	Max charge	Min charge	Useable range NEW
381.5	90%	343.35	76.3	267.05
Capacity when EOL		**Max charge**	**Min charge**	**Useable range EOL**
305.2	80%	244.16	61.04	183.12

Shift pattern	Shift start	Drive 1	Break 1	Drive 2	Break 2	Drive 3	Break 3	Drive 4	Break 4	Drive 5	Shift End	Total min	Total hrs
Shift 1	0	120	90	120	45	120	30	0	0	0	0	525	8.75
Shift 2	0	120	90	120	45	120	30	0	0	0	0	525	8.75
Shift 3												0	0

% opportunity charging	10	[%]	Amount of time available during the drive part of the shift

Results:





Battery life:

Number of full cycles per day:	4	estimated from SOC prediction
Number of shifts per day:	2	
Working days per year	281.25	based on annual operating hours and number of shifts

Months before battery EOL: 53

		Shift start	Drive 1	Break 1	Drive 2	Break 2	Drive 3	Break 3	Drive 4	Break 4	Drive 5	Shift End
SOC prediction (NEW battery)	Shift 1	90%	46%	90%	46%	90%	46%	90%	90%	90%	90%	90%
	Shift 2	90%	46%	90%	46%	90%	46%	90%	90%	90%	90%	90%
	Shift 3	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
SOC prediction (EOL battery)	Shift 1	80%	25%	80%	25%	80%	25%	80%	80%	80%	80%	80%
	Shift 2	80%	25%	80%	25%	80%	25%	80%	80%	80%	80%	80%
	Shift 3	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%

- **Severe duty operation**
- Coffee and Lunch breaks used for charging
- Large battery pack for range,
- Low C-rate charge due to current primary power source and Battery Chemistry Limitations
- Periodic Maintenance for Diesel is 500 Hours
- Periodic Maintenance EV is 2000 Hours

Nuvera Fuel Cells

Experienced

25-year history innovating hydrogen and fuel cell technology

Established

Built with the investment and expertise of major global brands

- Arthur D. Little
- DeNora
- Hess
- Renault
- Hyster-Yale Group

Engaged

Fuel cells in real-world motive applications

Certified

- ISO 9001-2015
- ISO 14001-2015
- OHSAS 18001

Nuvera technology powers some Hyster-Yale Group industrial vehicle products

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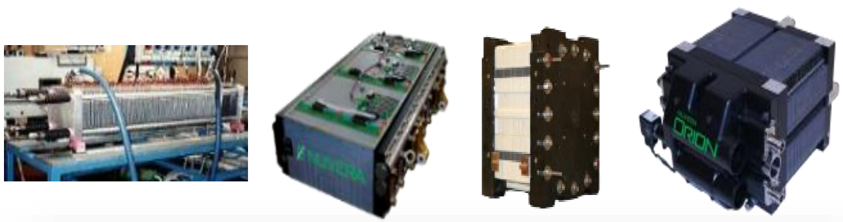
This strategic partnership with HYG provides Nuvera:

- Global reach
- Financial strength
- Strategic vision
- OEM-focus
- Unique capabilities

Generations of Fuel Cell Innovation



1993 → 2018

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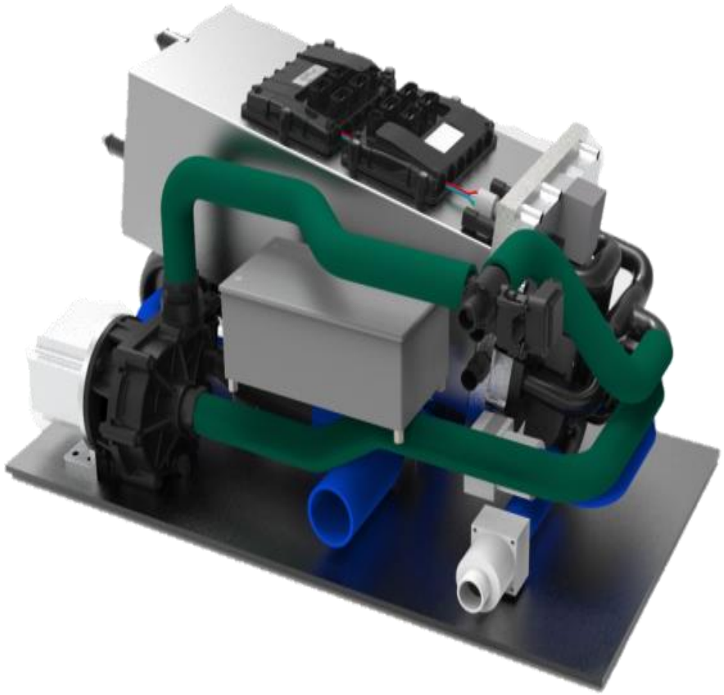
Fuel Cell Engines for Electric Top Loader (ETL)



Fuel Cell Engines for ETL
90 kW total (2 x 45 kW net)
Scale existing technology

Nuvera Tasks Overview

- Engine Requirements
- Component Scaling (Prototype v1)
- Integrated Engine (Prototype v2)
- Vehicle Engine Delivery
- Support Vehicle Integration
- Support Pre-Demonstration Activities
- Support Demonstration

June 2018 Status Deliverable

✓ Engine requirements summary – complete
✓ Prototype v1 design – complete
✓ Prototype v1 components – received/complete
✓ Prototype v1 build – complete
✓ Prototype v1 testing – in process (on schedule)
✓ Prototype v2 activity – in process (on schedule)

The Hydrogen Supply (1st Solution)

- Hydrogen is brought in by tanker but fuel needs to be transferred to storage vehicle with compressor that is in a fixed location
- Complete refuel in 15 minutes but Forklift could need to be driven up to 1.21 Km (0.75) miles to refuel

The Hydrogen Supply (2nd Solution)

- Compressed Hydrogen is delivered to wherever the truck is located. (same as current Diesel delivery)
- The refueler capacity needs to be doubled to meet Energy demand

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Operational challenge – Battery + Fuel Cell

Battery pack calculation model

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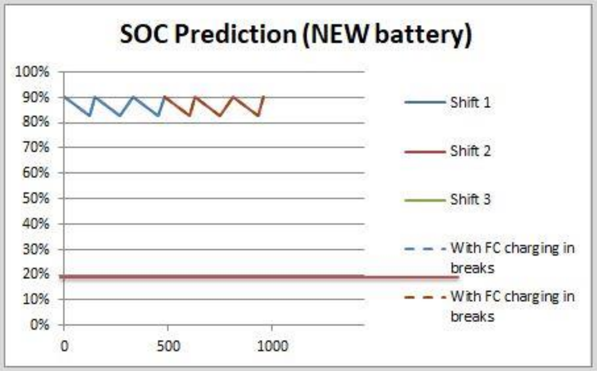
Inputs:

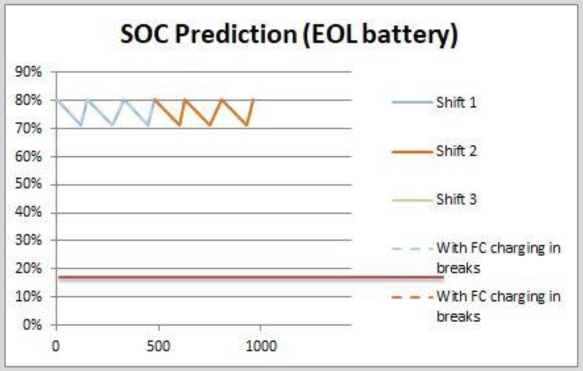
Average energy consumption	84	[kW]	Average energy consumption based on continuous driving according to prescribed pattern, calculated in virtual model
Opportunity charging	0	[kW]	Max charge rate during short stops on wireless charging system (max. 15 min.)
Normal charging	120	[kW]	Long term charging rate for overnight / lunch break charging
Annual operating hours	4500	[hr]	

				Capacity when New	*Max charge*	*Max charge*	*Min charge*	*Useable range NEW*
Battery config	112	[kWh]	Based on 9T battery configuration (1 pack is 28 kWh)	***112***	*90%*	*100.8*	*22.4*	***78.4***
Cycles to 80% capacity (EOL)	5000		Based on 9T NMC type batteries	***Capacity when EOL***		*Max charge*	*Min charge*	*Useable range EOL*
C-rate	1		Rated C-rate for number of cycles	***89.6***	*80%*	*71.68*	*17.92*	***53.76***
Fuel Cell	80	[kW]						

Shift pattern	Shift start	Drive 1	Break 1	Drive 2	Break 2	Drive 3	Break 3	Drive 4	Break 4	Drive 5	Shift End	Total min	Total hrs
Shift 1	0	120	30	120	60	120	30	0	0	0	0	480	8
Shift 2	0	120	30	120	60	120	30	0	0	0	0	480	8
Shift 3	0	0	0	0	0	0	0	0	0	0	0	0	0

Results:





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	Shift 2	90%	83%	90%	83%	90%	83%	90%	90%	90%	90%	90%
	Shift 3	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
SOC prediction (EOL battery)	Shift 1	80%	71%	80%	71%	80%	71%	80%	80%	80%	80%	80%
	Shift 2	80%	71%	80%	71%	80%	71%	80%	80%	80%	80%	80%
	Shift 3	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%

- **Severe duty operation**
- Added 90 kW Fuel Cell
- Reduced Battery Pack to 112kWh
- Periodic Maintenance on Fuel cell is 200 hours (Filter changes)

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Closing remarks

Heavy Duty:
We now have technologies that can make zero emissions work for heavy applications but each has its limitations using current Battery and Fuel Cell Technology.
A combination of technologies is required to achieve the required runtimes for the various Port duty cycles.

Reliable/Dependable:
Component development is at a stage that an electrical drivetrain is on a par, or better, performance wise, than an internal combustion engine but Fuel Cell reliability is still a work in progress

Total Cost of Ownership:
Return on investment is about 1.5 years for Electric Big Trucks and it’s supporting infrastructure using pure Battery Operation through

- Reduced maintenance
- Lower Li-Ion costs
- Lower Energy costs

Projected return on investment is about 2.5 years for the addition of a fuel cell and it’s supporting infrastructure.

Industry is really looking to Zero emissions and ready to invest in the infrastructure to support it

Close cooperation on vehicle AND infrastructure is needed

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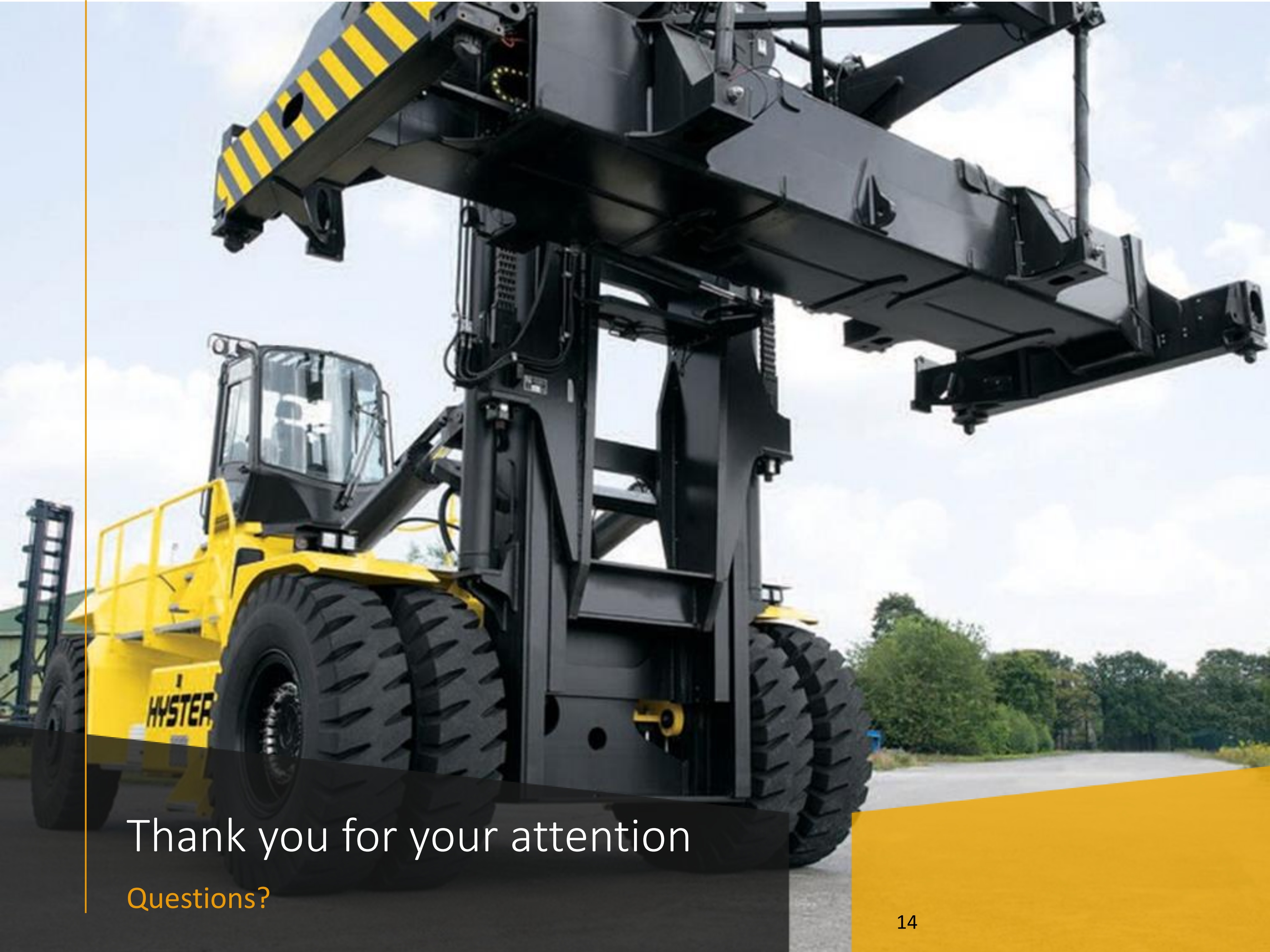

Thank you for your attention

Questions?