Technology road map for hybrid and electrical drivetrain of non-road mobile machinery

Tekes & FIMA & ABB in EVE/ECV/Tubridi
Panu Sainio, Tatiana Minav, Antti Lajunen, Kari Tammi / Aalto
Lasse Laurila, Juha Pyrhönen / LUT
Jenni Pippuri, Samu Kukkonen / VTT

This road map document has been reviewed and updated yearly during 2012–2017 in Tekes & FIMA & ABB project called Tubridi. This is 2017 version.
Contents

Introduction
1. Vision
   – Short term < 5 years
   – Medium term 5–10 years
   – Long term 10–30+ years
2. Required technology enablers
   – Identifying missing links
   – Technology competition
3. State of the art
   – Technology and components
   – Products
4. Drivers & trends
   – Regulations and policies
   – Market drivers
5. Actions
   – Exploiting the opportunities
   – Technology development
   – What to do if we want to meet the vision of this road map

Value creation
Introduction

• This technology road map for hybrid and electrical drivetrains of non-road mobile machinery (NRMM) has been prepared during “Future hybrid electric NRMM platform and its components” (Tubridi) work package of the Electric Commercial Vehicles (ECV) networked project, www.ecv.fi
  – Energy storage technologies such as batteries are not in the focus as they were the main topic of eStorage1-3 work packages in ECV networked project.

• Is it time for the next revolution? Please consider what happened in the 1950s when the diesel engine and hydraulics revolutionised the working machinery business.

• This road map is directed to people who are assessing the possibilities of electrification in their business. There is a very high number of different non-road mobile machinery on the market and observations discussed here have to be evaluated case by case.

• Summarising slide i.e. the next slide: please read the content of the boxes in numerical order from one to six. First box describes the vision while the rest of the boxes map the path towards that kind of a future.
Drivers & trends
- Understanding life cycle cost and TCO
- Policy to reduce CO\textsubscript{2} and other emissions
- Supply and demand of raw materials and their price
- Everything gets electrified and in Internet
- Laws and regulations

State of the art
- Necessary components are here but they are discrete, custom-made and manufactured in low volume
- Strategy: “find combustion engine, replace with electrical motor”
- Outcome not optimised in cost, reliability, usability, machine layout

Actions
1. Get your electrical mobile machinery platform ready
2. Create user demand from TCO
3. Search for/focus on right segment and try to spot the right moment
4. Start system integration and product development, i.e. stop the strategy “find combustion engine, replace with electrical motor”
5. New user experience from electrical control

Required technology enablers
- Energy and cost efficient electrical powertrain (machines, drives, energy storages)
- Automatic and easy charging and re-fuelling
- Appropriate manufacturing scale and facilities
- Low content of critical technologies

Summary

Vision
1. Majority of new machines in segments that are currently dominated by diesel-hydraulic solutions will be equipped with electrical powertrain by 2035
2. Autonomous solutions without human operator promote diversity of operations and new energy logistics
3. Multiple primary fuels: diesel, petrol, gas, hydrogen, electricity

NOTE: Target of the vision is to ensure success in the future!

Technology road map for hybrid and electrical drivetrain of non-road mobile machinery

Present

2035

Value creation
1. Vision

Value creation

1. Vision

2. Required technology enablers

3. State of the art

4. Drivers & trends

5. Actions
Vision – short & medium term (1/2)

Energy efficiency and energy consumption during life cycle become increasingly important issues

• Emission regulations and emission control or after treatment systems enter to all power classes (EU Stage V from 2019, regulated in all power classes).

• Consumption of fossil fuels increase and no decrease or shortages in crude oil production are foreseen in near future.

• Attitudes towards usage of fossil fuels are becoming less favourable, e.g. Paris COP21.

• Alternative fuels become more available which favours local fuel use and distribution (e.g. biofuels).

• Renewable energy sources (e.g. wind and solar) changes the traditional energy production and distribution (local vs. global energy production) \(\rightarrow\) need for local stationary energy storages.
Vision – short & medium term (2/2)

• Due to the existing electric powertrains in certain machinery applications (locomotives, forklifts etc.), the development of the electric powertrains will continue incrementally within these applications – This will not have major impact on the general development of electric powertrains.

• More manufacturers of mobile electric drive components and systems appear in specific applications first, and later in wider range of power levels.

• Resources put on battery technology and research on electric vehicles will have a positive effect on NRMM hybridisation and electrification.

• Gradual steps towards more electric NRMM are taken; auxiliary → power assist → full/plug in hybrid → full electric. First, hybrids with small batteries, and then bigger batteries with full hybrid powertrain.

• Successful demonstration machines will act as references and increase the confidence in electric NRMM.
Vision – long term

Mobile working machinery will be robotised in long term.

• Automation is a major driving force and has started technology trajectory leading to autonomous machines.

• Autonomous machines without human operator may promote diversity of size / power class of machines (when driver cost is not significant, machine can work 24/7 → machines can be smaller).

• Demands for energy efficiency and automation are favouring electric powertrain → we estimate in year 2035 half of new machines are equipped with electric powertrain.

Options to the companies seem to be a) work at full, b) work with small team or c) wait. Development happens in small steps. It is important to follow the field and be one of those taking steps towards fully electric working machine.
Vision – Electric components

Hybrid and electric powertrain component price forecast

<table>
<thead>
<tr>
<th>Component / Year</th>
<th>2014</th>
<th>2022</th>
<th>2030</th>
<th>Key performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller [$/unit]</td>
<td>900–1,000</td>
<td>1,000–1,100</td>
<td>1,200–1,300</td>
<td>Robustness</td>
</tr>
<tr>
<td>Inverter [$/kW]</td>
<td>30–35</td>
<td>28–30</td>
<td>24–26</td>
<td>Power density, control, cost</td>
</tr>
</tbody>
</table>
2. Required technology enablers

- **Value creation**
- **Vision**
- **Actions**
- **Drivers & trends**
- **State of the art**

**Required technology enablers**
Identified missing links

- No major breakthrough for batteries can be expected in near future.
- Feasibility of supercapacitors is approaching that of batteries.
  - However, supercapacitors are well suitable as single storage only for specific applications.
- Electric connectors with reasonable costs and easy assembly
- Components for mobile specifications at low cost and high number
- Missing subsystems: ultra compact diesel-generators and electric motor + high speed gears for traction.
- Manufacturing cost of electric motors can be too high.
- Standards and regulations – either they are missing or taken from totally different industry. Every industry has their own way of working and standards cannot be copied between techno-economical domains.
- Education – where to find talented people with multidisciplinary skills also for service and maintenance.
Technology competition, energy efficiency and environmental acceptance

• As hydraulics are being widely used in mobile machinery, a lot of efforts will be put on developing more energy efficient and powerful hydraulic systems → electro-hydraulics.

• New means to control hydraulics like digital hydraulics will enter to mass markets and boost energy efficiency and level of control.

• Electric powertrains have to compete against the traditional mechanical and hydraulic powertrains.

• Cost efficiency and energy efficiency may be improved through automation.

• Environmentally friendly biofuels and renewable energies will compete with conventional fossil fuels (Paris COP21).
Visions from other areas may be real eye-openers

Following “More Electric Aircraft” -theme

• Reducing size and number of engine driven pumps
• Increase capacity of on-board generators
• Secondary controls realised with electric actuators instead of hydraulic
• Reduction of hydraulic network extensions in airplanes, use of power packs locally, no need connection to central hydraulic network
• In primary control usage of electro-hydraulic actuator (EHA) as more electric solution
• Potentially reduced system weight, easy maintenance and advanced diagnostics and prognostics

http://m.hydraulicspneumatics.com/200/TechZone/HydraulicPumpsM/Article/False/83396/TechZone-HydraulicPumpsM
http://www.nottingham.ac.uk/aerospace/documents/moreelectricaircraftresearch.pdf
3. State of the art

Value creation

1. Vision

2. Required technology enablers

3. State of the art

4. Drivers & trends

5. Actions
Overview (1/2)

- Cost per capacity ratio of batteries is decreasing ~2…6% per year. Passenger cars are driving force for entry to mass markets.
- Integrated system components (gear motors, diesel generator sets, inverter motors, etc.) are under development → however, these are often application and utilisation specific systems (duty cycle).
- **Most of required technology is available** for adoption and, implementation of the components is under way.
- Software and control systems are becoming a part of components.
- Auxiliary system development is driven by energy consumption such as controlled fans and pumps, lights (= led) and HVAC (heating, ventilation and air conditioning by heat pump).
Overview (2/2)

- Electric motors and controllers with light duty automotive specifications are available.
- New players have entered to the component market
  - Not just components, but also system solutions (e.g. Allison transmission for heavy vehicles, Tesla, Chinese manufacturers)
- Industrial component manufacturers enter the market of mobile components → improved availability and competition.
- Electric powertrain has been de facto in high power heavy duty machinery (mining trucks, container handling) and on the rails
  - Applications which can be easily powered by electric grid such as port cranes, trains, metro and mining vehicles
Batteries

- Lithium-ion batteries have enabled a lot in last 10 years.
  - Hand-held electric tools (batteries) and mobile electronics

- There are fully electric and battery powered powertrains in small power classes, for instance forklifts, automated guided vehicles (AGVs)
  - Pricing, earning models and trends should be monitored from here?

- On-board electric power demand is increasing in all vehicles → higher voltage systems and larger battery capacities required for auxiliary systems.

- Major challenge: Recycle process, costs and second life of batteries?
  - Valuable materials are difficult to recycle from lithium based batteries → unprofitable business
  - Costs of batteries have to be managed during their lifecycle
  - For the time being, there is no simple solution for the second life of batteries
Electric motors (1/2)

- Asynchronous machines (ASMs) and permanent magnet synchronous machines (PMSMs) are typical choices today. Different reluctance machines such as switched reluctance machines (SRMs) are being actively investigated.
  - Motor type is chosen based on the operation, integration and costs requirements.
  - There is variation in specific torque, power and cost characteristics of different motor types.
- All means to lower costs and increase volumetric efficiency are demanded in vehicles and NRMMs → e.g. integration of gear and motor.
  - Key issue in the development of compact motors is cooling.
- ASMs/SRMs can bear temperatures up to +180 °C, PMSMs typically up to +80 °C.
- PMSMs allow wide geometrical variation in terms of rotor diameter vs. length.
- Reluctance machines are promising: low rotor losses, wide operation area and quite high specific torque (with proper cooling) are combined with easy manufacturing (recycling) process.
- Production for mass market with vehicle specifications; air cooled ASMs for industry are not the ones for vehicles.
Electric motors (2/2)

- Motor with integrated gear and controller can become a superior solution but standardisation of mechanical interfaces is needed.
- For integration development and technology, follow passenger cars and their motor / transmission / converter development
  - Mitsubishi Electric Develops EV Motor Drive System with Built-in Silicon Carbide Inverter 14.1 l, 60 kW. (2/2014)
- In mobile applications, lifetime of electric motor is usually long enough
  - Mechanical aspects like bearings and axial seals are the challenge
- No major improvements are foreseen for permanent magnet materials in motors, availability risks for raw materials can occur.
- In long term higher-conductivity wires, such as carbon nanotube (CNT) yarns, for the windings could reduce the motor losses and make it lighter and environmentally friendlier. (10/2014)
- Lifecycle costs (purchase and maintenance costs) might be an issue in the long term! SRMs might win this competition.
DC-voltage level?

- What will be the voltage ranges and de facto standards
  - DC 12 V (14.3 V) and DC 24 V (28.6 V)
  - DC 48 V systems are starting to be used in mild hybrids in passenger vehicles
  - AC 110/200, 240/400, 1000 V

- Losses are proportional to $\sim I^2 \rightarrow$ voltage up, current down $\rightarrow$ also less copper and smaller size. This is long term development leading to 400–800 V.

- Low voltage (24…100 VDC), existing components will be used in low power applications under 30 kW and mild hybrid systems such as power assist with electric auxiliary devices.

- Depending on the component availability, there can be several voltages: 12/24 V for accessories, 100–200 V (battery voltage) for pumps and fans and 600–800 V for powertrain.

- This item could be partly solved by some market leaders / machine segments. From these segments reasonably priced and commonly available components will be adopted to common mobile use.
Power converters (1/2)

- Versatile converters – one hardware offers several functionalities
  - DC/AC, DC/DC, AC/DC conversions with different control
- Substrates, power module packaging and wide band-gap semiconductors are modifying power modules.
- Silicon carbide (SiC) was a subject around 2005, and products are now available, e.g. SiC power MOSFETs
  - Single switch 1200 V, 60 A. Modules 1200 V, 880 A.
  - SiC components increase the efficiency of the whole electric drive.
    - Car makers agree that there is a 10% fuel savings when moving from silicon to SiC in hybrid vehicles
- GaN devices are progressing also, but at smaller power levels (600 V, 10 A)
Power converters (2/2)

- Temperature control / cooling demands
  - Allowable temperatures in power electronic components have developed favourably, i.e. increased
- Assembly has to be modular and easy, especially wires and connectors consume too much volume and are too difficult to make
  - Integration with the motor, rails instead of wires?
- Modular sizing and construction together with easy connections (cooling, high power and signals)
  - Perhaps something like hydraulic valve blocks
- In next slide, there is an estimation of the change
Example of SiC power device markets

SiC Power Device Market Size by Application

SiC market growth driven by adoption of advanced power electronics applications

CAGR: 34%

Source: Yole Développement – May 2013

Note:
1. Power factor correction; electric vehicle / hybrid electric vehicle; ultraviolet photoemission spectroscopy; photovoltaic inverters; motor alternating current drive
Software

- Simulation based software development
  - Modelling and simulation will be increasingly important in the future
  - Virtual simulation enables faster and cheaper product development

- MATLAB/Simulink or similar are tomorrow’s engineers’ “office software” like Word and Excel are today. Wide educational use supports MATLAB.

- Open source development vs. safety & security
  - Development of automation systems requires a lot of work.
  - Possible errors increase with the increased complexity. Therefore it is not foreseen that the customer or operators could access the core of the automation system.

- Service – remote control as part of business model both to machine manufacturer and operators.
New products

• Very large vs. very small machines = new power classes in different product segments, e.g. tractors.
• Developing countries where human labour is available and cost effective – will there be need for simple, cheaper machines?
• Repair and additional construction sites inside dense cities and underground – external skeleton type machines.
• Indoor and underground operational demand to be more common.
Production tools

- 3D printing is coming – material strength, costs and production time challenges are to be solved. Perhaps prototypes and very small series at this stage. Creating shapes, designs and customising?
- Multi material joints e.g. aluminium-copper becoming more common for low cost / weight power cables, cooling plates and corrosion protection.
- There can also be new machining methods to create function with reasonable costs like a predetermined friction stirred (FS) channel pattern that is produced in an aluminium work piece
  - Target is to obtain a component with specific mechanical and metallurgical properties. FS channels can be filled with other materials or be used only to reduce the component structural weight, optimise its stiffness or as cooling channels. This technology is in research phase.

Linear Friction Based Processing Technologies for Aluminium Alloys: Surfacing, Stir Welding and Stir Channelling, http://dx.doi.org/10.5772/52026
Charging – EV and PHEV systems (1/4)

• Heavy vehicle fleets such as electric NRMM or electric buses can be considered as a purchase of a system → customer needs to acquire vehicles and charging infrastructure.

• Different charging system options are available
  – Conductive chargers (plug or pantograph / current collector) either On-Board type or Off-Board type (DC-charger)
  – Inductive chargers (wireless energy transfer via magnetic field)

• On-board chargers are supplied with normal AC grid voltage or DC-voltage. These chargers benefit from simple infrastructure but have usually relatively low power.

• High power in on-board chargers increases weight and volume.
Charging – EV and PHEV systems (2/4)

- Off-board chargers can be fast charging units with high power capacity → up to 90 kW with CCS plug and 500 kW with pantographs.
- A charging unit communicates with the battery, supplies the power and is responsible for the charging process.
- Inductive chargers require equipment both at vehicle and infrastructure. These chargers are expensive but benefit from having no physical contacts. Power ranges from couple of kW’s to 200 kW.
- Standards are essential for interoperability and flexibility in choosing suppliers. Investments in charging infrastructure are expected to last longer than those of vehicles.
Charging – EV and PHEV systems (3/4)

• Off-board charging standards are available: Japanese originated from CHAdeMO and Europe/USA CCS.
• CCS standard set is considered to be extended to include high-power pantograph based charging systems utilising CCS technologies. This should work with buses and might offer interesting opportunities for example machines operating in city area maintenance.
• Low power on-board charging plugs and standards are available today for electric cars.
• On-board systems are often liquid cooled while off-board systems are air cooled. Air cooled solutions in dusty environment may need regular maintenance.
Charging – EV and PHEV systems (4/4)

• Inductive charging is yet to be standardised.
• Battery swapping used in forklifts: difficult to automatize and quite laborious, high investments especially in case of big batteries, vehicle layout should support this.
  – Tests on LHD loaders (load-haul-dump) have proved typical battery swap times of 15 min.
• Same supplier of the energy for the industrial process and for the mobile machinery might strengthen partnerships

- CCS provides energy from 20 to 200 kW according IEC 61851. Additionally e.g. a pantograf system is possible that could transfer energy up to 500 kW.
Electric powertrain dimensioning

• Transmissions are in NRMMs are traditionally based on diesel engine speed (up to 2500 rpm). Higher speeds can exists in implement and auxiliary drives (up to 4000 rpm).

• At the moment, there are electric motors capable up to 5 times higher speeds than diesel engines. This opens up new possibilities for the design of NRMM drivetrains.

• Dimensioning approaches of electric drivetrain speeds can be roughly divided into two categories:
  – High torque and low speed (0–4000 rpm) electric motor which fits directly or with some small (about 1:2) reduction into the existing drivetrain (expensive, typically includes rare earth metals, depending on motor type, may be bulky)
  – High power and high speed motor (0–10000 rpm or higher) which needs always some reduction (gearbox) between motor and existing drivetrain (cost efficient, compact, flexible design)
Synchronous belt drives (1/2)

• Transmissions with higher input speed (6000 rpm continuously) may need pressure lubrication that is used in conventional automatic transmissions of passenger cars and heavy goods vehicles (HGVs) but only rarely used in NRMM transmissions.

• To adapt high-speed motor to low-speed transmission needs additional reduction and one answer for that can be lubrication free synchronous belt transmission.

• Synchronous belts are developed to a level at which they are capable to transfer high power with high speed and still fulfil NRMM level lifetime and environmental requirements.

• Timing belts are often used in cam shaft drives of passenger car engines – those cases have created bad mouth over the years but also boosted development of belt drivers.
Synchronous belt drives (2/2)

1. Wide speed range (up to 10000 rpm or even 20000 rpm in low power applications) and wide power range (up to 500 kW)
2. Long enough lifetime for most NRMM applications, 10000 h or more
3. Wide temperature range (with some materials −54–+140 °C)
4. Depending on chosen material, a belt can be conductive or nonconductive
   • Non-conductive belt blocks possible rotor current going through bearings in secondary axle
   • Conductive belts can be used in ATEX-environments
5. Insensitive for humidity and small particle dust
6. Good selection in off-the-shelf components
7. Generally good chemical durability
8. High accuracy, minimal backlash, no slip
9. Allows small misalignments
10. High efficiency (up to 98%)
11. No need for lubrication
12. Maintenance free

The International Energy Agency’s paper on “Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems” advises to use synchronous belts as an improvement possibility for energy savings. The US Department of Energy also encourages the use of synchronous belts in all motor installations to maintain an overall efficiency rating of 98% across a wide load range.

Source: Hutchinson Timing Belt Leaflet, June 2013
Hydraulics driven by electric motors

Displacement control (method: changing pump output flow)
- a) variable displacement pump + constant speed motor
- b) variable displacement pump + variable speed motor
- c) fixed displacement pump + variable speed motor

Electro-hydraulic actuators (EHA)
(compact pack of actuator, pump, electric motor)

Moving from mechanical and hydro-mechanical control systems to electronic solutions in following concepts
- **Fly-by-wire** and **Drive-by-wire** concepts
- **More Electric Aircrafts** (MEA) concept
- **Steer-by-wire**, power steering
State of the art: examples

Volvo L220F Hybrid wheel loader

Powertrain configuration and main components
- Diesel-electrical parallel hybrid
- Volvo D12D LB E3 engine, 261 kW (SAE J1995 gross)
- Energy storage: battery

Enables
- Boosting during start-up and at breakout
- Regenerating power during normal operations
- Minimising idling which accounts for up to 40% of a wheel loader’s running time

Benefits
- Fuel savings up to 10%

Caterpillar D7E Diesel-Electric Hybrid Tractor

Powertrain configuration and main components
- Diesel-electrical powertrain
- 175 kW diesel engine
- Energy storage: no energy storage

Enables
- Downsizing the diesel engine
- No gears to shift

Benefits
- 10-30% lower fuel consumption
- Better manoeuvrability → moving more cubic yards per fuel gallon
- Fewer moving parts → longer lifespan
State of the art: examples

ProSilva 910EH electric hybrid forest harvester
Powertrain configuration and main components
- Diesel-electrical parallel hybrid
- 60 kW diesel engine (in non-hybrid 155 kW)
- Energy storage: battery
Enables
- Downsizing the diesel engine
- Peak shaving: electrical drive and energy reservoirs for taking care of the high peak power demands
Benefits
- Reduction of exhaust emissions and fuel consumption

Hitachi Hybrid Excavator ZH200-5B
Powertrain configuration and main components
- Diesel-hydraulic powertrain with electrical assist and swing motors and drives
- Energy storage: capacitor
Enables
- Hybridisation of the swing motion*: 1) storing energy in the capacitor during the swing deceleration; 2) electrical assistance of the swing acceleration
- Boosting the hydraulic system with electrical assist motor
Benefits
- Reduction of fuel consumption and CO₂ by up to 20%

*primary target of hybridisation in the machine
State of the art: examples

John Deere 644K hybrid wheel loader
Powertrain configuration and main components
- Diesel-electrical powertrain
- 6.8-L IT4/Stage IIIB engine, 171 kW
- Energy storage: no energy storage. Equipped with brake resistor.

Enables
- Running diesel engine at constant speed
- Utilisation of the braking energy in assisting the engine in hydraulic processes

Benefits
- Up to 25% composite fuel consumption reduction

Kalmar hybrid straddle and shuttle carriers
Powertrain configuration and main components
- Diesel-electrical hybrid
- Energy storage: battery
- Automated start-stop system to balance between energy sources

Enables
- Utilisation of the electrical braking and spreader lowering energy

Benefits
- Fuel savings up to 40%
- Lower noise
- Less pollution
State of the art: examples

Konecranes SMV 4531 TB5 HLT hybrid reach stacker
Powertrain configuration and main components
- Diesel-electrical series hybrid
- Energy storage: supercapacitor
Enables
- Electrical energy recovery
- Peak shaving: boosting the diesel-powered electrical generator during peak power demand
Benefits
- Estimated fuel consumption 30% lower than in conventional machines

KESLA C860 Hybrid wood chipper
Powertrain configuration and main components
- Diesel-electrical series hybrid
- Engine: Volvo Penta TAD572VE (160 kW / 910 Nm) EU Stage IV / EPA Tier 4 Final
- Energy storage: supercapacitor (by Visedo)
Enables
- Downsizing the diesel engine and its utilisation at optimal speed
- Elimination of traditional drivetrain
Benefits
- Reduced fuel consumption, 20-35% lower, and emissions
State of the art: examples

Huddig Tigon construction machinery

Powertrain configuration and main components
- Diesel-electrical hybrid
- Energy storage: 25 kWh Lithium battery
- Both energy sources, diesel engine and battery, can be used for the operating the hydraulics or for propulsion

Enables
- Fully electrical operation possible

Benefits
- 30% higher output power than in diesel powered
- 25% reduction in fuel consumption

Logset 12H GTE HYBRID harvester

Powertrain configuration and main components
- Diesel-electrical hybrid
- Engine: Agco Power 74 AWF, Tier IV Final (4), 220 kW at 1900 rpm, 1200 Nm at 1500 rpm
- Electrical motor: 175 kW at 2100 rpm, 800 Nm at 0-2100 rpm

Enables
- Uplifted performance
- Peak shaving with the electrical drive
- Stable engine performance

Benefits
- Lower fuel consumption and running costs
- Less exhaust gases

2015

Huddig 1, 2

2016

Logset 1, 2
State of the art: examples

Kalmar FastCharge™ solution

- Powertrain configuration and main components
  - Electrical powertrain
  - Fast charging concept similar as in large capacity electrical buses
- Enables
  - Smaller number of vehicle components
- Benefits
  - Up to 50% increased efficiency in comparison with diesel/electrical drive
  - Zero local emissions
  - Reduced noise and maintenance

Atlas Copco Scooptram ST7 Battery

- Powertrain configuration and main components
  - Electrical powertrain
  - Artisan 1200 Series traction motor - 630 VAC / 108 kW, 149 kW peak, single power inverter
  - Energy storage: Artisan battery, 165 kWh, LiFePO4, 630 VDC
  - Charger system: Artisan 65 kW Master Service, input voltage 575 VAC
- Enables
  - Zero emission drive
  - Fossil fuel free operation with renewable electricity
- Benefits
  - 80% lower energy consumption compared to diesel machines

2016
State of the art: examples

Your machine here?

Future visions

Valtra ANTS

Volvo SfinX

Concept tractor

Concept of the tractor of the future
Designer
Prithu Paul

Valtra

Volvo

Aalto University

LUT
Lappeenranta University of Technology

VTT
4. Drivers & trends

Value creation

1. Vision
2. Required technology enablers
3. State of the art
4. Drivers & trends
5. Actions
EU strategy and policies

- EU strategy on reduction of CO₂ emissions
  - Objective: reduction of Europe’s greenhouse gas emissions by 80–95% compared to the 1990 levels by the year 2050
  - Besides the obvious, the reduction of the CO₂ emissions is beneficial also for the following reasons
    - Dependence on the oil is reduced that consequently balances the geopolitical power relations
    - The target level cannot be reached simply by savings. Potential for new business in the field of clean technologies

- The CO₂ emission reduction objectives are complemented with other policies or declarations such as with the “White Paper” that maps the path to competitive and resource efficient transportation in Europe

Emission standards: Tier V

• Upcoming EU Stage V regulation will impose new limitations on the particle mass and particle number emissions of non-road diesel engines
  – Alternative fuels, e.g. biofuels are seen as one solution and are associated with the need for restricting of methane emissions and other non-regulated emissions such as aldehyde emissions
  – Change from Tier IV to Tier V is not cosmetic. Instead, it is almost certain that the particle filters have to be widely applied in working machine engines.
• Regulations of Tier V do not concern the fuel consumption, i.e. no limitations are imposed.
Energy prices example: crude oil price development

Crude oil price development (oil.fi, Thomson Reuters).

Crude oil prices react to a variety of geopolitical and economic events.

Idealised fossil and nuclear energy depletion curves of the world considering the present availability and the current rate of consumption (Bose 2013).
Market entry is done by steps

<table>
<thead>
<tr>
<th>Electric auxiliaries i.e. electric high power components in fans, pumps with voltage over classical 12/24 V, for example 42 or 96 V</th>
<th>More characteristic</th>
<th>More power to existing machine</th>
<th>Down sized diesel</th>
<th>Pure electric solution</th>
<th>Lower energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatically stops/starts diesel engine for waiting times and can sustain for example HVAC for during that</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uses an electric motor to assist a diesel engine and/or can deliver significant electric power to implements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recharges batteries from a pantograph or a socket for extending or enabling all-electric operation continuously or in periods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Efficiency / performance / readiness for automation
Summary on drivers

Market drivers or obstacles for electric work machines

- Work performance
  - Goal 1. More performance
  - Goal 2. Better fuel economy
  - Goal 3. Better fuel economy
  - Goal 4. Better service response

- Safety and Quality
  - Advanced safety features
  - Remote monitoring
  - Reliability and robustness
  - Image and emotions
  - ISO 26262 (IEC 61508)
  - Nose restrictions (level and time window)
  - Environmental zones in cities
  - Special environments like mines, harbors, airports etc.

- Customer / work site restrictions
  - Definition of performance; only needed id purchased
  - Incentives and taxation
  - Resale value vs. leasing
  - Less diesel emissions at site
  - Maintenance cost, lower and prediction
  - New business models; machine hours vs. tons per hour
  - Gas engines, especially when gas is made by electrolyze or similar process
  - Developing internal combustion engines, for sure yes but they do have their own limitations
  - Multi fuel / new fuels. And if fuel do change in road cars, how will it affect to NRMM

- Total cost of ownership TCO
  - Tier 4 and future
  - Optional Materials
  - Exhaust after treatment costs and need of volume
  - Need and demand of monitoring machines in field
  - Work cycles definition and diesel emissions in site
  - Exhaust after treatment costs and their weight /volume

- Competing technologies development

- Emission and diagnostics

- Work comfort and occupational safety
  - Noise, vibration and harshness
  - Better work environment (less heat, less exhaust)
  - Smooth traction, response times and dynamics

- Fuel economy / CO2
  - Power classes 20-1000 kW - same main powertrain
  - Driver education (Air bus)
  - Different topologies / power train architectures
  - Forward compatible / upgrading
  - Market area / customer variants

- Variant management

- Power classes 20-1000 kW - same main powertrain
- Driver education (Air bus)
- Different topologies / power train architectures
- Forward compatible / upgrading
- Market area / customer variants

Applied and expanded from article “In search of the optimal future power train”, Schmidt-Sante, T., Hammer, J., MTZ 07-08/2012. Original article discussed subject from passenger car point of view.
5. Actions

Value creation

1. Vision

2. Required technology enablers

3. State of the art

4. Drivers & trends

5. Actions
Exploiting the opportunities and preparing for changes

• It is important to understand the profitable market sectors for hybrid and electric machines.
• For faster introduction and adoption of electric powertrains, it is crucial to have strong
  – Understanding about the cost effectiveness of electric powertrains
  – Collaboration between industry, research and legislative bodies
  – Benefit from technology hypes of the consumer market products
• Because of the limited resources of raw materials and energy, relying on only one technology can be risky.
• Due to the economy driven world politics, the prices of energy and materials are vulnerable and subject to substantial fluctuation
  – E.g. the changes in crude oil price have been rather significant
Hypotheses to be confirmed

- Hybridisation is a method for risk management of battery technology.
- Electric powertrain is an innovation platform: to manage market and customer segmentation and tool for technology risk management.
- Electric control enhances the user experience that will be even more important selling point in the future.
- There will be intermediate solutions in electrification such as power take-off (PTO) electric generators in agriculture in near future.
- New earning and funding models in services and leasing will emerge – vehicle and machine sharing and strategic partnerships between companies.
- Large scale electrification of NRMM will require higher voltage systems – there will probably be different system voltage levels depending on the application.
Approach on technology development

• **Patience** is acceptable especially in system innovations, where multiple actors need to cooperate and develop technology simultaneously.

• Innovation journey include meeting new partners such as electric utility companies → Open mind has an important impact on innovation.

• Technological hype is a necessity to draw attention and get funding
  – E.g. investors may benefit from hype by higher returns

• Hype is typically followed by a disappointment, or at least, it may turn out that the progress is done by incremental innovations only.

• After hype there is “down time”, then begins real growth and work
  – Experienced and networked engineers are valuable for long-term development

Applied from the article "Technological hype and disappointment: lessons from hydrogen and fuel cell case", Bakker, S., Budde, B., EVS 26, 2012
What to do if we want to meet the vision of this road map (1/2)

• Let’s not just follow what others are doing, but create the future by ourselves!
• Demonstrations are needed for technology validation.
• Means for the road map realisation
  – Tekes program? New Tekes program on mobile working machines (not just electric vehicles)
    • Finnish NRMM industry is big, it deserves its own program
    • First the more electric mobile working machines, then automatized versions
  – EU related (Horizon 2020), FIMA project with Tekes?
  – Research cases with companies making
    • NRMM and mobile components for electric drivetrain
• What do we see as interesting research topics in road map?
  – Scope of the further activities, for instance development of components or development of integrated powertrain solutions in accordance with upcoming regulations?
What to do if we want to meet the vision of this road map (2/2)

Possible topics

• Challenges in complete implementation of a hybrid drive system in a NRMM
  – System automation, making the whole system to work

• Taking steps towards full robotisation
  – Electric powertrain is an innovation platform for intelligent control; making every driver intelligent, energy efficient, productive and capable to operate in difficult environment
  – Remote control and remote drive

• Development of standards and regulations
  – Participating actively in the process

• Create needs for customers (as well as understanding on the state of the art solutions).
Drivers & trends

State of the art

Value creation

Actions

Required technology enablers

Vision
Follow up

• This work has been carried out in Tubridi work package of Electric commercial vehicles (ECV) networked project. ECV was active from 2012 to 2016.
• Feedback, comments and particularly, challenging of our views and estimates are welcomed

Panu Sainio  panu.sainio@aalto.fi  +358 50 5678 396
Lasse Laurila  lasse.laurila@lut.fi  +358 40 837 2164
Jenni Pippuri  jenni.pippuri@vtt.fi  +358 41 455 0427