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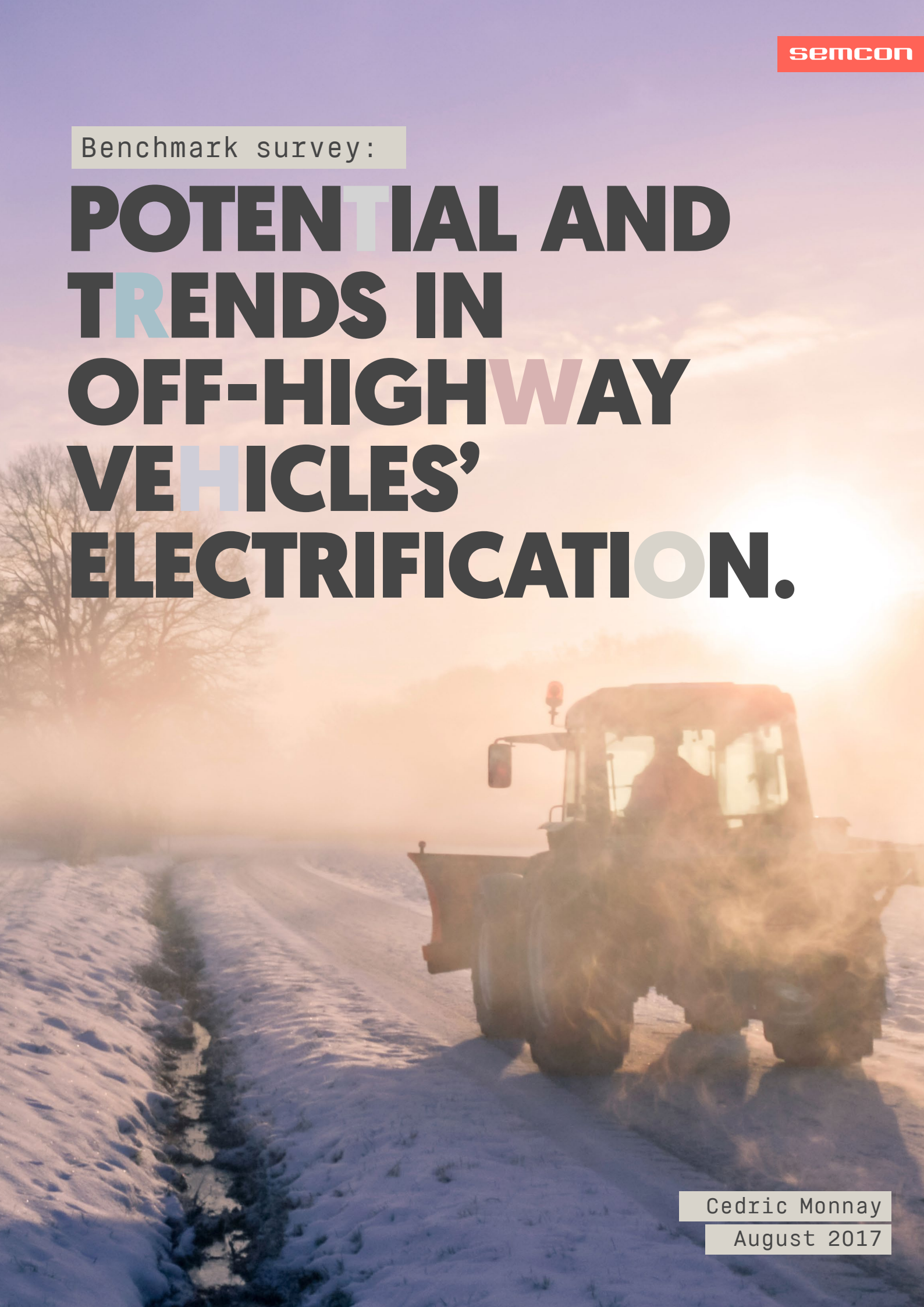
Benchmark survey:

POTENTIAL AND TRENDS IN OFF-HIGHWAY VEHICLES' ELECTRIFICATION.



Cedric Monnay

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Intro.

In the off-highway machinery industry, the development of electrical hybrid systems and vehicles continues to progress, as does the use of sensors and electronics. By 2018, the hybrid powertrain market is expected to account for 3% of the global off-highway powertrain market [1].

At the global level, strengthened emissions regulations and persistently volatile fuel prices drive the electrification of off-highway machinery, and as such, every major original equipment manufacturer in key markets currently conducts research on, if not also works to develop, electrified powertrains. However, given the consensus that no single true alternative energy strategy exists, the off-highway machinery industry continues to investigate different electrification levels, such as mild hybridization or full electrification.

Today, developing integrated and overall smarter systems by using sensors and other electronics allow many companies to meet goals related to efficiency and emissions reductions, thereby supporting increased hybridization and full-vehicle electrification. Among the many prototypes developed, some hybrid off-highway vehicles have been introduced into the market and there shown significant gains in performance and considerable reductions in operating costs.

In this report, we recount the tremendous progress and achievements in the electrification of off-highway machinery, as well as forecast future developments in light of global trends.

Benefits from using hybrid and electric technology.

In the United States and the European Union, non-road engines remain a significant source of air pollutant emissions. In 2011, non-road vehicles and equipment (also called implements) were responsible for ~20–45% and ~15–20% of mobile-origin particulate matter and nitrogen dioxide emissions, respectively, in the United States and European Union [2]. In response, increasingly stringent regulatory programs have spurred not only developments in engine design and after-treatment technologies, but also accelerated technology transfer from on-road to non-road machinery.

In 2018, the European Commission will launch the world's toughest emission standards for non-road machinery, known as the Stage V program. For some machinery applications, one technology response predicted by the International Council on Clean Transportation is the implementation of on-road emissions control strategies in non-road engines [2]. However, that organization has identified several barriers, including the cost of advanced emission control technologies, the packaging constraints and the challenges presented by the differences between non-road and on-road duty cycles. In a more radical response, the non-road machinery industry continues to develop alternatives, among which a key technology able to accommodate both current and future emissions regulations for all non-road machinery applications is hybrid and electric technology.

For the mobile off-road industry, however, regulatory programs are not the sole drivers of the development of new machinery. End-consumers' operating costs also drive product improvements and, in that regard, electrification of machinery and its equipment shows great potential. Such advances portend considerable reductions in fuel consumption and minimizes product downtime by way of increased reliability. Moreover, electrification offers considerable benefits in terms of controllability and precision, which can enable operators to save both time and money.

As original equipment manufacturers have become more aware of the benefits of hybrid and electric technology, innovative products have continued to be developed. The following insights present those achievements and highlight the potential of off-highway electrification. Additional achievements are described in the appendices.

Fuel economy

"**Save up to** an average **of 25% in fuel consumption**" with a hybrid excavator [4]

"**25% average reduction** in fuel consumption" with a hybrid wheel loader [5]

"**Fuel consumption is reduced by up to 50%** on the overall duty cycle" in applications such as mobile cranes [6]

With hybrid systems, **fuel consumption can be cut by 30% in the near to medium term and up to 50% in the longer term [3]**.

Additional achievements are described in Appendix 1

With the electrification of driveline systems, the biggest cost reduction will come primarily through lower fuel consumption.

In that regard, engine downsizing and energy capturing systems show significant gains in fuel economy. Other efficiency improvements are achieved through a range of options such as: stop-start, engine operating hours, accessories like the fans running on electric power, energy recovery from the driveline and hydraulic system.

Increased productivity

"36% higher torque, 6% greater horsepower" with an electrically powered, high clearance sprayer [7]

A hybrid dozer **"improves productivity by 10% and reduces lifetime operating cost with 10%"** [8]

A hybrid powertrain for a stone crusher has a **"great impact on productivity with a 40% increase"** [9]

"Power electric drives on implements **offer 10% more power**" [8]

Additional achievements are described in Appendix 2

How much work can be done within a set period of time?

By enabling efficient energy recovery and increasing controllability, electrification allows more to be done within a set cycle time. Moreover, thanks to electrically driven implements, easier connection and increased modularity can be achieved.

Greater reliability

“60% fewer transmission parts” [10]

28 drives are suitable for beneficial electrification on agricultural machines [11]

The aeronautic industry has chosen electric technology over others due to its high reliability. Maintenance requirements will be reduced as more electric drives replace the existing hydraulic and mechanical ones.

Another advantage of electrification lies in the reduction of the number of transmission parts, resulting in considerably less maintenance and reduced product downtime.

New environmental standards

New business opportunities in environmentally sensitive locations

Emissions regulations are increasing requirements for more environmentally friendly off-highway machinery, creating new challenges for OEMs. Using emissions regulations to their fullest advantage, hybridization can lead to lower after-treatment for emission controls [12], thereby minimizing the cost of the machine.

Machines offering such sustainable technology will also enable customers to win contracts in environmentally sensitive locations, where the advantage of much quieter machines due to hybridization will also be a benefit.

What's next on the technology horizon?

Overall system optimization

Great potential lies in the optimization of overall systems, as demonstrated by the e-RoGator and X concept from AGCO. Although electrification of machines has some value in itself, working to improve the entire electrified machinery system (e.g., hybrid tractors with implements) adds value in terms of yield and helps reduce maintenance costs.

Less costly, more efficient components

Progress in other industries in terms of fuel-saving technologies, hybrid drive systems, and electrification can contribute to the development of the hybrid off-highway vehicle market. Cheaper and more efficient components will emerge on the market, and accelerate the technology transfer between the on-road and non-road industries. A recent example concerns 48-volt solutions for mild hybridization in the automotive industry, the adoption of which has already attracted the attention of the agricultural and off-highway sectors.

The non-road machinery industry can also benefit from innovations in electrohydraulic systems, which have improved noise reduction and energy savings [19].

Connectivity and smart system

Smart electrified systems that provide information to operators and machines can further improve efficiency and productivity:

- Information provided to the machines can boost precision and reliability by allowing more accurate control and monitoring (e.g., via global positioning systems and machine-to-machine communication)

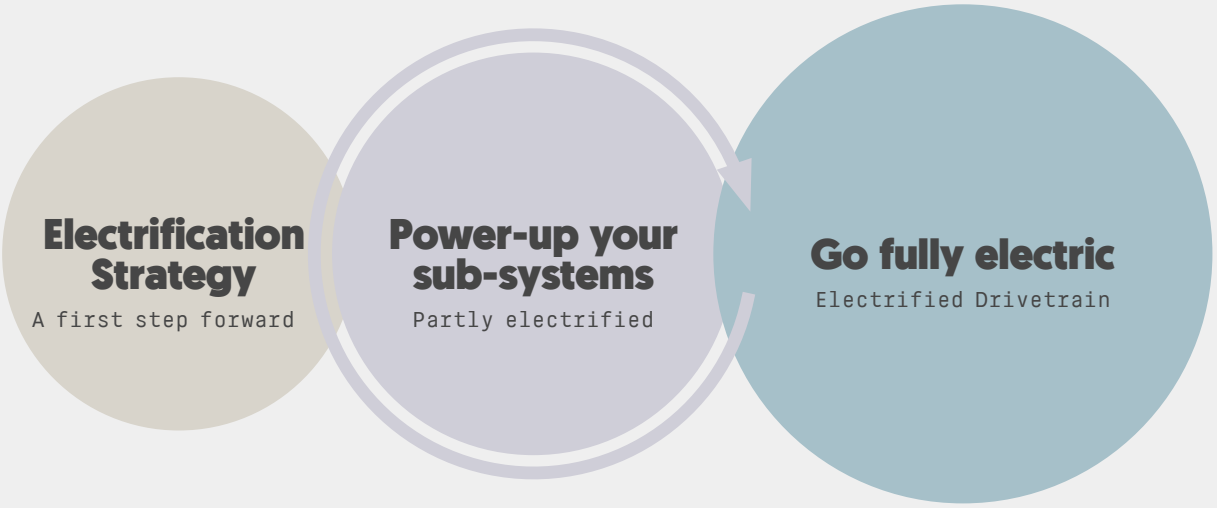
- For operators, analyzing that information and using it to enhance decision-making can improve productivity.

Such smart systems are already available in other industries and will continue to progress, especially as the costs of feedback devices and controllers continue to drop.

Get started in three steps.

Semcon can provide support throughout the whole development chain from early strategy assessments to final verification by:

- Establishing a strategy to reach new businesses
- Enhancing the product with electrified sub-systems
- Integrating electrically powered drivetrains for full environmental and productivity benefits.



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Appendix.

Appendix 1: Fuel economy

Major companies have built prototypes or introduced electric and hybrid powertrains on the market showing excellent results:

- Ricardo has developed a hybrid excavator demonstrator to show the benefits of their flywheel energy storage system and is claiming “10% fuel savings” [13]. With 65% lower cost than battery hybrid systems and still delivering 80% of the fuel economy, the flywheel hybrid system may be a good fit for machines with low volume production.
- Komatsu’s H215LC-1 hybrid excavator is claimed to reduce fuel consumption by up to an average of 25% and also offers a similar reduction in emissions [4].

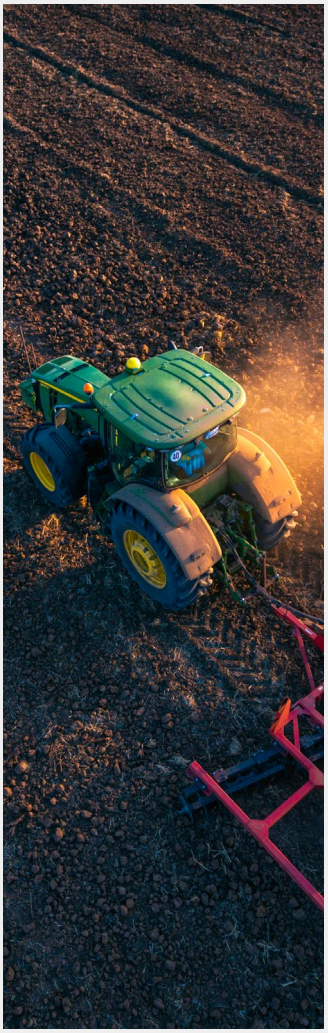
- John Deere is marketing a 644K hybrid electric wheel loader that claims to reduce fuel consumption by up to 25% [5].
- Volvo Construction Equipment has developed 2 prototypes for the transport stage in a quarry: a hybrid wheel loader delivering up to 50% improved fuel efficiency and a fully electric autonomous load carrier. By combining electromobility and self-driving, the project predicts up to a 95% reduction in carbon emissions and up to a 25% reduction in the total cost of ownership for this load carrier [14].

- The combination of a diesel engine and six electric motors provided plenty of power for the first electro hybrid forwarder in the world. El-forest's calculations point to 30-35 percent lower fuel consumption compared to traditional forwarders, cutting costs and reducing emissions of greenhouse gases [15].

- The Belarus 3023 tractor's electro mechanical drivetrain, with a 300 hp engine powering a 220 kW generator, is claimed to reduce fuel consumption reduction by 15-20%. Optional equipment includes an electric cooling fan for the radiator and an electromechanical front PTO shaft that can operate at speeds independent of the engine's rpm [8].

- By taking over the functions of traditional mechanical and hydraulic linkages, pumps and gear sets, electrified platforms can control tractor components such as the coolant pump and fan, at speeds that are independent of the engine's rpm. This can result in fuel savings of up to 13 percent, as shown on the John Deere 7530 E Premium tractor [16].

- Although PTO and hydraulic power systems are well established and effective for today's applications, the search for more versatile and efficient power transfer continues. One alternative is electric power. Researchers have identified 28 drives on agricultural machines that are potentially suitable for beneficial electrification [11].



- Cummins has presented the advantages of plug-in hybrids for applications such as mobile cranes, which use diesel for transport and plug-in power for crane operation [6]. This technology enables silent operation with reduced tailpipe emissions on urban construction sites and fuel consumption is reduced by up to 50% on the overall duty cycle.

Appendix 2: Increased productivity

Electrification is not all about saving fuel. Manufacturers have increased their products' productivity thanks to the controllability, accuracy and performance provided by hybrid and electric technologies:

- AGCO has developed a prototype, electrically powered, high clearance sprayer. It provides 36% higher torque, 6% greater horsepower, uses 70% less hydraulic fluid and offers a 20% increase in fuel economy according to Dave Lovel, AGCO manager for Application Equipment [7].

- An electric hybrid powertrain, called the ZF TERRA+, was developed by ZF for agricultural tractors and self-propelled harvesters [8]. A starter generator module integrated into the transmission provides electric energy for auxiliaries and implements. ZF claims that when used in a tractor "the optimum operation of electrified auxiliaries can achieve consumption benefits of about 5% on the average". Moreover, compared to conventional hydraulic drives, power electric drives on implements offer 10% more power according to ZF.

- Using a diesel-over-electric drivetrain for primary propulsion and electric accessories, including AC compressor and water pump, the Caterpillar's D7E dozer delivers up to 30 percent better fuel efficiency, improves productivity by 10%, and reduces lifetime operating costs by 10% [8].

- The Rockster Hybrid Impact Crusher R1100DE stone crusher is equipped with a hybrid powertrain that includes the use of supercapacitors. According to Rockster, the technology can save upwards of 16,000 L of diesel fuel per year for a single machine. And while the use of a hybrid powertrain allowed for 30% lower fuel consumption, it had an even greater impact on productivity with a 40% increase [9].

- An all-electric spreader from Rauch offers a clear example of the benefits of electric drives. Drive speeds are controlled independently of tractor ground speed or rpm and are easier to adjust while spinner discs can be shut down more quickly thanks to electrical braking of disc motors. The system is also easy to connect, no need to deal with hydraulics. Finally, up to 3 to 6 times higher efficiency is achieved in comparison with a hydraulic spreader [17].

- Kinze's 4900 planter is available with electrically driven seed and insecticide metering for highly-accurate variable rate application of crop inputs [8].

- Amazone has developed electric drives for precision seeding and a fully electric chemical applicator. The "axis" spreader showed that an electric drive configuration was most efficient and had the best tractor/implement fuel economy when compared to two hydraulic drive configurations and one mechanical drive configuration on this same model [18].

Appendix 3: Links

1 Strategic outlook of Global Hybridization Trends in Select Off-Highway Commercial Vehicle Markets, Frost & Sullivan, February 2013.

2. Technology pathways for diesel engines used in non-road vehicles and equipment, ICCT, 2016

3. http://www.oemoffhighway.com/electronics/smart-systems/gps/article/12006423/tremendous-progress-in-electrification

4. http://www.komatsuamerica.com/equipment/excavators/25001-70000lbs/hb215lc-1

5. https://www.deere.com/en_US/corporate/our_company/news_and_media/press_releases/2013/construction/2013feb6_woc_644k.page

6. http://articles.sae.org/15445/

7. http://www.agriculture.com/machinery/farm-implements/sprayers/sprayers-of-future_230-ar13731

8. Agricultural industry advanced vehicle technology: benchmark study for reduction in petroleum use, US department of Energy National Laboratory, Sept 2014.

9. http://www.oemoffhighway.com/electronics/power-systems/electric-motors/article/12171843/are-petrol-prices-affecting-the-electrification-of-industrial-electric-vehicles

10. High voltage electrification of tractor and agricultural machinery-A review, Energy conversion and management, Moreda, G.P.,M.A Munoz-Garcia, and P. Barreiro.

11. Prospects of Hybrid Systems on Agricultural Machinery, GSTF J AGric Eng 1.1, 2014.

12. http://articles.sae.org/15441/

13. https://ricardo.com/news-and-media/press-releases/ricardo-to-reveal-high-efficiency-flywheel-energy

14. https://www.volvoce.com/united-states/en-us/about-us/news/2017/volvo-ce-unveils-the-next-generation-of-its-electric-load-carrier-concept/

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16. http://www.farmindustrynews.com/tractors/coming-soon-electric-tractors

17. http://www.clubofbologna.org/ew/documents/KNR_Rauch.pdf

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19. https://www.boschrexroth.com/en/xc/products/product-groups/industrial-hydraulics/the-fitness-program-for-hydraulics