

New Approach to Life Cycle Analysis of Self – Propelled Agricultural Machines

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ABSTRACT

The aim of this paper is to present some findings in life cycle analysis developed in industries connected to agricultural machinery, and to give an approach in developing new generation of self-propelled agricultural machines. Life cycle analysis is described in 4 phases with a given accent on the final phase of life cycle analysis – the disposal phase. This phase is shown through comparison with End of life Vehicle approach in automotive industry and disposal techniques developing in various environmental fields. Finally, benefit that could arise from implementing this approach in agricultural machines is explained as a conclusion.

Key words: Life cycle analysis, agricultural machines

1. INTRODUCTION

The environmental movement started in the 1970es attempting to address gross pollution of water and air resources. After the 1980s, a new philosophy arose promoting prevention instead of control and correction. On the Earth Summit held in Rio de Janeiro in June 1992, the assembled leaders signed the Framework Convention on Climate Change and the Convention on Biological Diversity; endorsed the Rio Declaration and the Forest Principles; and adopted Agenda 21, a plan for achieving sustainable development in the 21st century. The ISO created Technical Committee 207 on Environmental Management in 1993 with the scope of the committee as follows: "standardization in the field of environmental management tools and systems." As a result of developing standard, series of ISO 1404x standards have been developed that deal with life cycle analysis, as a standardized approach in dealing with life cycle analysis.

Joint with the standard, different approaches have been developed concerning life cycle analysis, most determining Product Life Cycle (PLC) based upon the biological life cycle. Areas of concern were phases of the life cycle and determination of their influence on the environment. Prior to the pressure of key environmental drivers, life cycle was analyzed as a set of the following phases – development, production and use. The ISO 1404x series of standard determines product life cycle "from the cradle to the grave" covering production (including extraction of raw materials), use and disposal whilst some new approaches determine that phases should cover development, production, use and disposal, table 1.

Table 1. Phases of life cycle analysis

Phases of life cycle	Old approach	ISO 1404x	New approach
R&D	✓		✓
Production	✓	✓	✓
Use	✓	✓	✓
Disposal		✓	✓

Therefore, in modern theory of analyzing a life cycle of a self-propelled machine, this cycle can be considered as a cycle that consist of two main periods - the period of creation of a machine and the period of exploitation of the machine. The creation period covers two phases – research and development and production, while exploitation covers other two phases – use of the machine and disposal of the machine, figure 1 (Djekic *et.al.*, 2000).

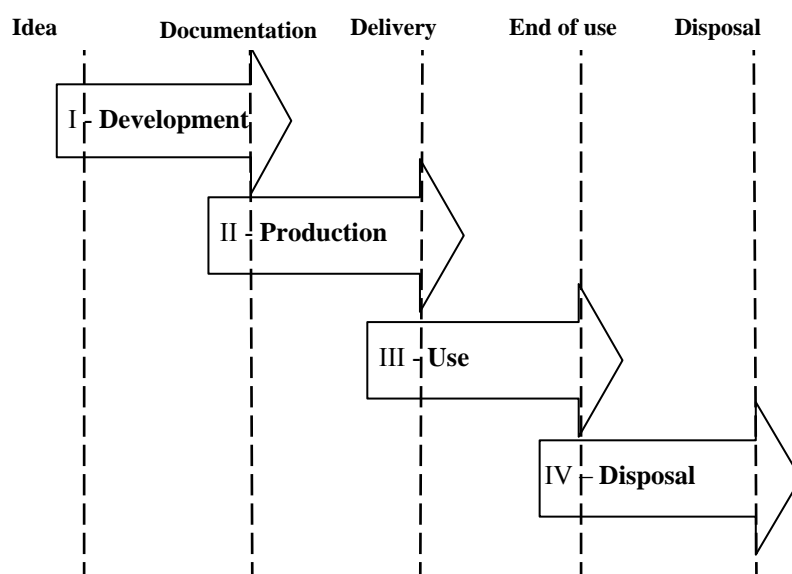


Figure 1. Overview of life-cycle analysis of a self-propelled agricultural machine in four phases

The R&D phase represents the phase of creating an agricultural machine from defining the solution, through realizing the process of designing the machine to developing its prototype. Next phase is the phase when (serial) production of the machine starts and when responsibility and authority of this phase is beyond control of the R&D department. This phase usually consists of the activities of production of agricultural machines and distribution of agricultural machines to the sales points.

While the production phase of a serial production may continue, each machine from the moment they are sold begin their working phase, every machine for itself. They may change owners, but as long as they are used, this activity falls in the working phase. This phase can be considered also as the guarantee period of the life time of an agricultural machine and the period for all kinds of servicing activities. Final phase, is the phase when the machine ends its life-time and problems with its disposal arise - the disposal phase.

As shown above, for further life cycle analysis the four phases can also be observed depending on the influence they have on the number of machines they affect (for an individual machine or the whole series of machines), table 2.

Table 2. Influence on a phase to number of machines

Phases of life cycle	Series of machines	One machine
R&D	✓	
Production	✓	✓
Use		✓
Disposal		✓

2. CRITICAL ISSUES IN 4 PHASES

Every phase in life cycle analysis has some critical issues that have to be considered. Speaking about research and development, critical issues are:

- what determines a new generation of self-propelled machines (new design, new esthetics, new engine, small marketing modifications, productivity improvements, etc.)?
- can modifications realized during production phase (verification and validation of new machines) be considered as research and development?
- How does this phase affect the environment?

In the production, key parameter that has to be identified is how to determine when to stop the production of the agricultural machine, and depending on the methodology used, analyzing aspects and impacts on the environment. Some of criteria for ending the production process are as follows:

- no more interest on the market,
- new generation of agricultural machines have been developed,
- competition has developed improved models,
- legislature, etc.

Also, it should be specified whether the production period means the period of production of the complete agricultural machine or it can be understood as the period until spare parts are produced. In many cases, a new generation of agricultural machines consist of a great number of parts that are identical to parts that belong to the previous generation.

Environmental issues that arise during the production phase are usually dealt through implementation of environmental management systems either through the EMS model given in ISO 14001 or through internal EMS developed by each of the manufacturers, (Deere, 2004). As an objective evidence of this, some manufacturers are granted with appropriate certificates or being ranked in 100 Best Corporate Citizen List, etc.

During the working phase, the phase when the machine operates on the field, critical environmental issues are as follows:

- pollution of the engine,
- consumption of natural resources (type of fuel),
- maintenance (disposal of lubricants, oils, etc.),
- disposal of worn-out spare parts.

As previously mentioned, consideration of environmental movement insists on paying a great attention on the whole life cycle, but especially on the disposal period of a product, in this case, of an agricultural machine. Therefore, the agricultural machine is not analyzed only for its need to satisfy the requirements of the customer in realizing its activities in the field, but also to satisfy the requirement of its reproduction or use by another customer.

This means that the life-cycle of an agricultural machines doesn't end at the time when its production (or the production of spare parts) stops. The machine continues to live as long as it exist, no matter if it is in working condition or not. The main problem that must be solved in this period is:

- to define what is the condition to determine the end of a life-cycle?
- to define the time when the machine ends its life-cycle?

Among many reasons for ending the use of an agricultural machines, main four factors that determine a life-time are as follows:

- decrease of the value of the machine due to depreciation although the machine is functional and useful;
- losing its functional features (out of order, worn out, lack of reliability);
- machine can not fulfill new requirements in the supply chain (specific condition from a food processing plant for harvesting machines)
- due to is inefficiency (high costs for maintenance and spare parts, low reliability).

Maintenance of the machine can prolong the period of exploitation, that is the period when the agricultural machine is in working conditions. According to (Kato *et. al.*, 2004), periods in which a machine operates, are as follows,:

- period of using the machine by the first customer;
- using second-hand machine;
- period of not using the machine.

Machines in good condition can postpone the disposal of a machine. The price of a second-hand machine depends on three levels, figure 2:

- level of physical deterioration (graph A)
- level of functional deterioration (graph B)
- model change (graph C)

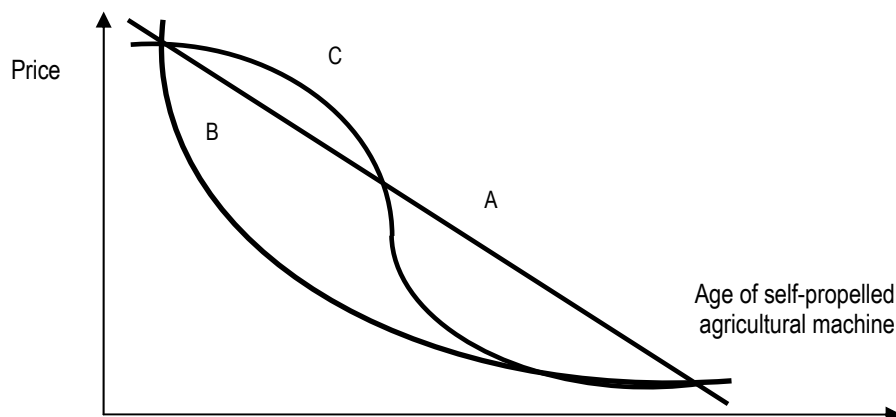


Figure 2. Price curves of reused machines

When the machine ends its working period, the disposal period begins. For a simplified explanation of this period, the agricultural machine must be analyzed from its possibility of reproduction in any way. Most elements of an agricultural machine can be divided into one of the following categories:

- elements that are easily replaceable and whose working period is shorter than designed working period of the machine;
- elements that can be replaced, but their replacements practically means replacement of the whole machine;
- elements that can be reproduced and/or recycled, after their replacement;
- elements that can not be reproduced and/or recycled, after their replacement;
- elements categorized by type (metal parts, plastic parts, hazardous materials, glass, rubber, electric/electronic parts, etc.) and further analysis of their aspects and impacts to the environment.

2.1 End of Life Strategy

In analyzing the disposal period of an agricultural machine, it is important to know all elements/parts of the machine once they are dismantled and the environmental value of its constituent parts. In solving machine's end of life characterization, there are many approaches but for agricultural machines two of these methods are appropriate - LCA - Life Cycle Analysis and EOL - End of Life Vehicle. The best is to combine these two approaches since LCA methods are developed in ISO 1404x series of standards while EOL Strategy is strongly developed in automotive industry.

The LCA method analyzes the following aspects of agricultural machines:

- impact of the manufacturing process (contamination of land, air emission, waste water pollution, use of natural resources, etc.)

- influence of the machine during its use to the environment (gas exhaust, contamination of soil, etc.)
- influence of the machine when end of life occurs.

On the other side, End of Life Strategy is only focused on the period when a commercial vehicle is disposed. Vehicles, essential to society, are continually increasing in use. However, throughout their life cycle, vehicles impact the environment in several ways: energy and resource consumption, waste generation during manufacturing and use, and disposal at the end of their useful lives. In September 2000, the European Parliament passed the European Union End-of-Life Vehicles (ELV) Directive, a set of requirements related to the storage and recycling of vehicles after they are no longer in use (Directive 2000/53/EC of the European Parliament and the Council of the European Union). This directive requires that vehicle manufacturers provide the information needed for dismantling a vehicle, such as details of vehicle components and location of hazardous substances, to authorized recycling facilities.

The regulatory approach to automobile recycling in Japan is similar and most of the selected items (i.e., schedule, car manufacturer's obligations, costs) are similar. In both cases, the car manufacturer has an essential role in the infrastructure system of waste prevention, collection, and treatment of ELV. End of Life Vehicle Directive dictates that manufacturers must make available dismantling instructions/data to facilitate the correct and safe depollution and dismantling of End of Life Vehicles.

About 75 percent of end-of-life vehicles, mainly metals, are recyclable in the European Union. The rest (~25%) of the vehicle is considered waste and generally goes to landfills. Environmental legislation of the European Union requires the reduction of this waste to a maximum of 5 percent by 2015 with the following schedule: no later than 1 January 2006, for all end-of-life vehicles, the reuse and recovery shall be increased to a minimum of 85% by an average weight per vehicle and year. Within the same time limit the reuse and recycling shall be increased to a minimum of 80% by an average weight per vehicle and year; No later than 1 January 2015, for all end-of-life vehicles, the reuse and recovery shall be increased to a minimum of 95% by an average weight per vehicle and year. Within the same time limit, the re-use and recycling shall be increased to a minimum of 85% by an average weight per vehicle and year. The ultimate goal of this directive is to put only 5% of ELV residues (ASR) into landfills.

Recycling of ELV incorporates the recycling itself, recovery, and reuse. The driving force, criteria, and concept for ELV recycling result from different factors that have changed with time, as published in the EU Directive (Directive, 2000). About 8 million to 9 million ELV per year are estimated to be recycled in the E.U. countries. The ELV recyclable rate of 75–80% is higher than that of simpler products such as glass containers, newspapers, and/or aluminum beverage cans.

Concerning agricultural machines no such initiative is taken yet. However, speaking about tractors and combines as two major machines in agricultural engineering industry, it can be considered that if one may emphasize that a passenger car contains about 15,000 parts, in complex agricultural machine, such as combines, number of parts can be even double. According to (FAOSTAT, 2005), there are over 4.2 million combines world-wide and over than 27 million tractors world-wide in use at the moment.

The End-Of-Life (EOL) strategy described above, aims at a reduction of the environmental impact of discarded products, a reduction of the use of virgin materials and a decrease of the total amount of waste. These strategies can be classified according to a specific hierarchy. Environmental hierarchy of EOL strategies is as follows, figure 3:

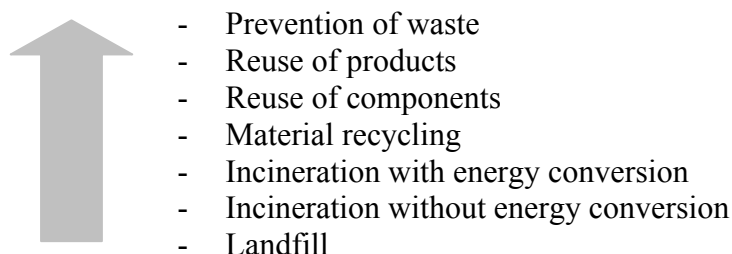


Figure 3. Environmental hierarchy of EOL Strategy

Similar to the supply chain, a post-usage supply chain can be introduced, as follows:

User >>>>> EOL organization >>>>> Interested party

Where:

- User is a farmer or an organization that is the final user of the machine before its destruction
- EOL organization is an End of Life organization that takes care of the machine until its final dismantling and disposal
- Interested party is a party that is in charge of solving the problems with dismantled parts such as landfill, manufacturer that uses parts for recycling, etc.

Requirements given upon an EOL Organization, figure 4, are:

- Final user gives / sells the machine to an EOL Organization,
- All EOL organization respect all environmental, health and safety legal and other requirements to which they subscribe,
- Their objective has to decrease the total percentage of unsolved waste,
- Unsolved waste that can not be solved with any of 4R techniques may not dispose such waste on landfills,
- Strong feedback communication channels have to be generated in all phases of the life cycle of an agricultural machine to enable an environmental sound new generation of machines.

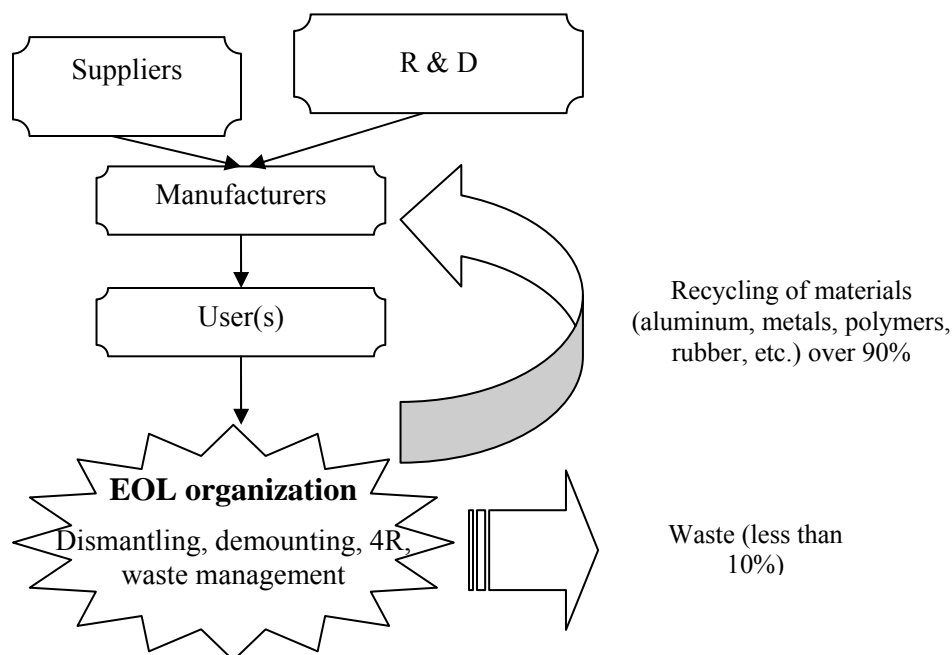


Figure 4. EOL Approach of Self-Propelled Agricultural Machines

In an increasingly global economy, the goals of this and similar directives (such as Waste of Electric and Electronic Equipment Directive, etc.) are becoming a sensitive issue for worldwide vehicle production. To enable implementation of such an approach in industry of agricultural machines, it is important to:

- endeavor to reduce the use of hazardous substances when designing agricultural machines;
- design and produce agricultural machines which facilitate the dismantling, re-use, recovery and recycling of end-of-life agricultural machines;
- increase the use of recycled materials in agricultural machines manufacture;
- develop recycling technologies;
- produce machines with recycled component and market this advantage;
- implement a system of deregistration upon presentation of a certificate of destruction;
- introduce licensed ELV collectors and dismantlers;
- introduce Certificate of destruction as necessary evidence to de-register the machine (de-registration must be done by the machine's last owner at a licensed dismantler).

2.2 Disposal techniques

A number of waste prevention techniques are available, and they are commonly summarized as the so-called 4Rs: Reduction, Reuse, Recycling and Recovery. Reduction, reuse and recycling

are known in the industry as the 3Rs. Companies sometimes focus only on the first three in resolving waste management problems. In more innovative companies, 4Rs solutions often emerge as a result of industry benchmarking or technological breakthroughs.

Another important question in decreasing the impact of self propelled agricultural machines is the cost of its dismantling (disassembly). Mostly three occasions may occur:

- A – one to one disassembly (one handling action for each connection in order to unfasten parts during disassembly)
- B – one to many disassembly (need one action to unfasten a set of connections)
- C – destroying the entire machine (presses)

Figure 5 shows relation of costs of decreasing influence on environment. Graph B can not be presented since it depends on the methodology of gathering elements (similar materials, functional entities, etc.).

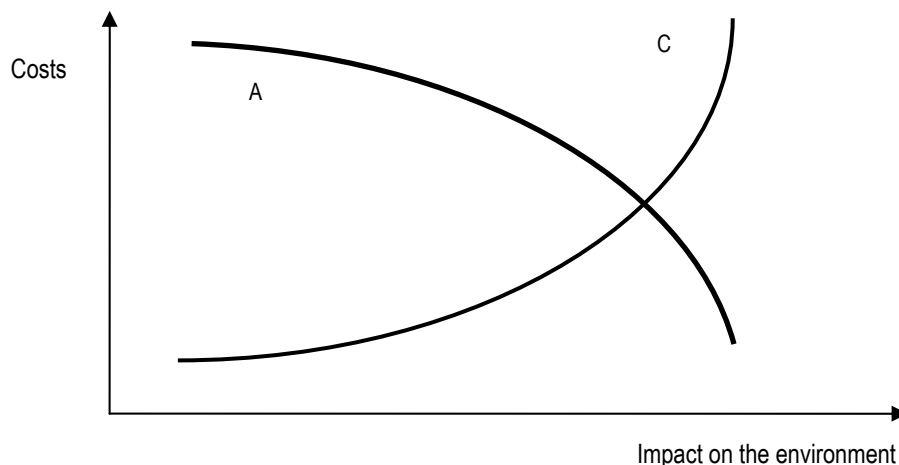


Figure 5. Costs of decreasing impact on the environment A, (B) C method

Focus on an agricultural machine as a high value product directs to a conclusion that only if the disassembly process costs can be reduced, reuse with disassembly becomes optimal and this approach may be considered. Introduction of one-to-many disassembly techniques can be of much help since the disassembly time is no longer dependant on the amount of parts, it is more realistic to reduce the time with 75% without affecting the handling time. Since one trigger can dismantle several parts, there is a clear potential for realizing time reductions, (Willems *et. al.*, 2004).

Disposal methodology directly depend on the following factors:

- material built in the agricultural machines;
- dismantling methods used and 4R approach;
- international and domestic legal and other environmental requirements (and their implementation within the society);
- environmental awareness of the community.

Guidance on depolluting for agricultural machines can be as follows - modified from (Depolluting EOL Vehicles, 2002):

- Disconnect Battery and remove from machine, get heater control to maximum, remove fuel cap and oil filler cap;
- Remove wheels and tires from the machine and remove Lead balancing weights;
- Check for and remove any items marked hazardous (e.g. mercury switches);
- De-bowse petrol / diesel using specialist equipment, drain engine / transmission oils, drain anti-freeze and screen wash, drain suspension system (e.g. shock absorbers) fluids, drain brake fluid from brake lines and master cylinder, drain power-assisted steering system (all fluids to be stored in separate containers in bunded storage area prior to specialist recovery/disposal).

After depolluting, dismantling can be completed and machine can be destroyed. Example of transferring the purpose of dismantled spare parts through recycling can be shown in the following way (modified from Car recycling – Europe, 2002):

- Body and door (steel) → agricultural machine parts, general steel products
- Engine (steel, aluminum) → Engines and aluminum products
- Transmission (steel, aluminum) → General steel products, aluminum products
- Wheel (steel, aluminum) → Car parts, general steel products, aluminum products
- Tire (rubber) → Raw material, alternative fuel for cement
- Window (glass) → Tiles, etc.
- Seat (urethane foam, fiber) → Soundproofing materials for vehicles and agricultural machines
- Hood (steel) → agricultural machines parts, general steel products
- Engine oil (oil) → Alternative fuel for boilers and incinerators
- Coolant (alcohol) → Alternative fuel for boilers and incinerators
- Gear oil (oil) → Alternative fuel for boilers and incinerators
- Bumper (resin) → Bumpers, interior parts, toolboxes, etc.
- Battery (lead) → Batteries
- Catalytic converter (rare metals) → Catalytic converters

3. CONCLUSIONS

Sustainable quality (comes from sustainable development and quality) of an agricultural machine is level of achieved quality with no harm to the environment, pursuing competitiveness and sustainability of agricultural machines industry and society concerned.

As a conclusion, some new items and challenges have been arisen to R&D units in developing new generations of agricultural machines. The main goal is to achieve a high level of recycling and reuse rates and to enhance an "ideal" model of sustainable vicious circle of developing agricultural machines, figure 6.

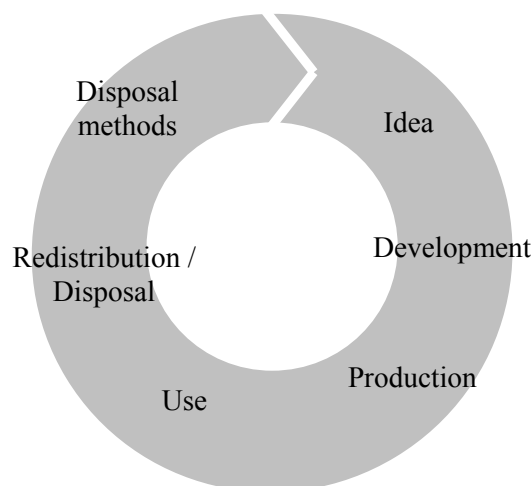


Figure 6. Sustainable vicious circle of agricultural machines

The new approach should use the following techniques (Djekic 2006):

- prevention of pollution and waste generation in early phases of development
- development of new technologies for recycling in all phases of the LCA of an agricultural machine
- production of new machines that consist of recycled old machines
- easy dismantling of machines (with Dismantling Manuals and guidelines for disposing elements and parts)
- Introduction of a Certificate of Destruction given to the final user of an agricultural machine

Assuming the following:

- average usage period of an agricultural self propelled machine is 10 years (in developed countries such as US and EU tractor is used 5 years or around 10,000 working hours while for combines it is 8 years or around 2,000 working hours (Vieweg, *et.al.*, 2001), in developing countries it can go up to 20 years)
- average weight of an agricultural machine is:
 - o for combines around 10 tons according to (Landmaschinen Katalog, 2004) weight is in the interval from 8 to 20 tonnes
 - o for tractors around 3,5 tons according to (Tractor Catalogue, 2004), weight of tractors is in the interval of 2 to 15 tons
- 15% of machines are out of use (sale of 1,5% of new machines per annum)

Simple calculation takes us to 4,14 million of old tractors and 0,64 million old combines. Multiplied with average weight we can assume that there is over 14,5 million tons of waste from disposed tractors and 6,4 million tons of disposed combines, in total about 20 million tons of waste in the moment. This can be used as a sales strategy "old for new" for solving increasing global problems in selling new combines and tractors, as well as problems with disposal of old machines. Certificate of destruction could be used as a bonus for investing in purchasing new machines.

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