Testing the three-phase technology for harvesting biomass from wetlands

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SUMMARY

Many protected wetlands in Poland require special care to restore and protect them as breeding areas for endangered bird species. As machinery for this purpose, adapted tracked snow groomers, tracked trailers and wheeled tractors are outdated and not eco-friendly. The Industrial Institute of Agricultural Engineering (PIMR) has designed and developed new-generation machinery that will be more useful in formal paludiculture. The PIMR three-phase technology (T-PT) improves the efficiency of vehicle movement making it less damaging to protected wetlands, and allows non-stop collection of a whole swath. The bales produced are rolled over the ground as a biomass train to storage locations at the field margin. Key features of T-PT that contribute to protection of the wetlands and the wider environment are: a) the delta tracks of the vehicles, which make grooved paths (depth ~ 30 mm) but do not damage the surface structure; b) non-stop swath collection, which improves engine efficiency and reduces fuel consumption; and c) the use of 'EcoSafe FR' biodegradable fluid in the power hydraulics, which means that there is no pollution of water in the case of spillage.

KEY WORDS: biodegradable hydraulic fluid, bird breeding grounds, environment, tracked vehicle

INTRODUCTION

Many wetlands and fen peatlands in Poland and elsewhere require special care to restore and protect them as breeding areas for endangered bird species. Often, they are mown periodically to prevent succession of the vegetation, which creates a need for the mown biomass to be cleared from the immediate area. The results of inadequate biomass management can be seen in Great Britain, where biomass bales may be left to rot and become overgrown with bushes and small trees, or the mown biomass is burnt on the site (Mills 2013). Biomass burning is not safe for peatlands and causes nuisance air pollution for people and animals. Polish farmers working on peatlands use wheeled tractors with agricultural trailers and adapted snow groomers (ratracs) or similar tracked machines for cutting, collecting and transporting biomass. These outdated vehicles and technologies are unsatisfactory because they cause habitat damage (repeated crossings of the same area destroy the root mat of the vegetation) and pollution by spilling hydraulic mineral oils. Wheeled tractors loaded with biomass bales damage the peatlands by forming ruts 0.4–0.6 m deep (Dubowski *et al*. 2012), whereas snow groomers adapted by farmers to work as tracked mowers on wetlands destroy the top layer of plant roots (Dubowski *et al*. 2014a). Damage is also caused by the tracked trailers used for transporting biomass bales on wetlands (Krogulec & Gatkowski 2013).

In Poland, poorly serviced snow groomers use mineral oils rather than biodegradable ones. In the eventuality of equipment failure, mineral oil spills are a major source of surface and groundwater pollution (Zembrowski *et al*. 2014), as one cubic centimetre of mineral oil can contaminate 5000 cubic centimetres of water. In Germany, a PistenBully ratrac was converted into a biomass harvester that used AVIA SYNTOFLUID PE-B 30 for the hydraulic system and biodegradable oil (Wichtmann *et al.* 2016, p. 66, Box 4.4). The technical leaflet for this hydraulic fluid recommends it for use in agriculture and forestry, but there is a puzzling concluding remark to the effect that this lubricant must not enter the sewage system, soil or groundwater (Avia Bantleon 2015).

Generally, no remedial action is taken after mineral oil spills, especially on Natura 2000 sites and protected wetlands in National Parks (Dubowski *et al.* 2014a). There have been some recent changes in this regard; for instance, there is now a regulation in Biebrza National Park stipulating that every tracked vehicle should carry a sorbent for removal of spilt mineral oil. However, where the terrain is covered by water, sorbent is not an effective solution in terms of environmental protection.

Ratrac tracks cause great damage to peatland habitats because their steel or aluminum bars (grousers) destroy the top layer of plant roots and level the uneven terrain in such a way that protected areas which should be restored for threatened bird

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species look more like airport runways than natural peatlands (Dubowski *et al.* 2013, 2014a). Moreover, the traditional snow groomer turns by directing power to one track while the other is dragged along, and this is particularly damaging to both the vegetation and the ground surface. The repeated use of ratracs at Biebrza National Park over the course of several years damaged and levelled the peatlands and thus proved to be environmentally hazardous (Banaszuk *et al.* 2016). Similar problems associated with the use of converted snow groomers for harvesting and moving biomass in wet and rewetted peatlands have also been noticed in Germany (Schröder *et al.* 2015, Wichtmann *et al.* 2016).

Damage to the soil surface results in significant slowing of the re-growth of plants and of the rebuilding of their root structure, reducing the strength and load-carrying capacity of peatland surfaces so that tracked vehicles and wheeled tractors can no longer move safely on them after a few years (Zembrowski *et al*. 2014). An attempt to measure the shear modulus using a portable spiked plate (Figure 1) (Ala-Ilomaki 2013) failed at the very first attempt because the plate punctured the root layer and sank up to top of the handle. This test was conducted at the entrance to the wetlands known as Czerwona Lawka, where ratracs have been harvesting and transporting biomass for several years.

Ratrac tracks, especially those with sharp-edged bars, not only level the ground but also shave the root layer. A very thin carrier layer on terrain which has been degraded in this way will not be able to withstand the pressure of a snow groomer, introducing the possibility of the vehicle sinking and a threat to life for the driver. Therefore, vehicle operations must stop temporarily whilst the ground is thoroughly checked.

These negative outcomes from the use of outdated machines and technologies for biomass removal in protected areas, especially National Parks, has led to research at PIMR and the consequent development of new and more environmentally friendly tracked vehicles, machines, tools and technologies for the three phases of mowing, harvesting and transporting biomass (Dubowski *et al.* 2013, Zembrowski 2009, 2013; Zembrowski *et al.* 2014, 2016; Patents: PL 216591 (2010), PCT/PL2011/000065 (2011), PL 220296 (2012), PL 220683 (2012), PL 228367 (2015), PL 228850 (2015), P. 420773 (2016)). We refer to this approach as the 'three-phase technology' (T-PT).

In this article we report on the latest versions of research vehicles and equipment designed or rebuilt by PIMR towards realising full implementation of the three phases of the T-PT, and on field trials carried out in Poland during 2015.

Figure 1. Using a portable spiked plate (made by PIMR) with torque wrench to test surface strength in a sward of common reed on organic muck soil, water table depth 0.5 m. Photo: PIMR archive.

FIELD SITES

The field trials described here were carried out on reedbeds in the village of Byszewice near Chodziez (meadows of the Notec River) and in the village of Biala near Trzcianka (flood polder of the Notec River). The soils at these two sites were, respectively, organic muck soil (pH 5.5–5.7) and moderately humified peat. At both of these sites, water table depth was 0.3–1 m and the vegetation was common reed (Owczarzak *et al.* 2015).

THE PIMR TRACKED TRACTOR

The tracked vehicles used in the T-PT have practically no deleterious effects on the wetlands for the following reasons: 1) no pollution because a high quality fire-resistant biodegradable fluid (EcoSafe FR; ACTI 2016) is used in the power hydraulics; 2) delta tracks only make grooved paths (depth of indentation around 30 mm), even in tight corners; and

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3) no process of ground levelling is observed, and plants grow back quite rapidly in the grooves.

The weight of a tracked tractor (Dubowski *et al.* 2013) is about 5 t and its ground pressure is around 11 kPa (110 g cm^{-2}). The PIMR Kubota M9960 tracked tractor used for harvesting biomass weighs 4.74 t and the pressure of its tracks on the ground is around 17 kPa (170 g cm^{-2}). Each track of the PIMR tractor and trailer is delta (Δ) shaped (2.06 m long, 0.95 m wide) and independently powered by a hydraulic engine. The tracks on the two sides of the vehicle are capable of running at different speeds during turns, depending whether they are located on the inside or the outside of the turning circle. This feature aims to minimise the ground damage caused by turning the vehicle on peatlands and other wetlands (Dubowski *et al.* 2013).

THE FRONT-MOUNTED MOWER UNIT

For cutting and conditioning biomass and forming swath, a front-mounted disc mower with rake and tedder was rebuilt and upgraded by PIMR. This involved the addition of a biomass conditioner equipped with knives and double mulching flails (Figure 2). The biomass conditioner was mounted directly behind the disc mower (Patent P. 420773 (2016)). Mowed reed or grass is conditioned by simultaneously breaking and cutting it into smaller pieces of length approximately 30 cm. After this treatment the biomass can be moved into the space of the finger-wheel rake and tedder much more easily. Finally, swath is laid on the stubble off the track of the vehicle, where it is left for a period of 2–3 weeks. This allows natural seeding, which ensures that adequate biodiversity is maintained in protected areas and on sites under restoration as breeding areas for birds.

NON-STOP SWATH COLLECTING/BALING

The non-stop swath collecting unit consists of a swath pick-up attachment and two belt conveyors mounted on the tracked tractor. The unit for forming bales is constructed on the tracked trailer, and provides a spacious feeding hopper plus a round bale

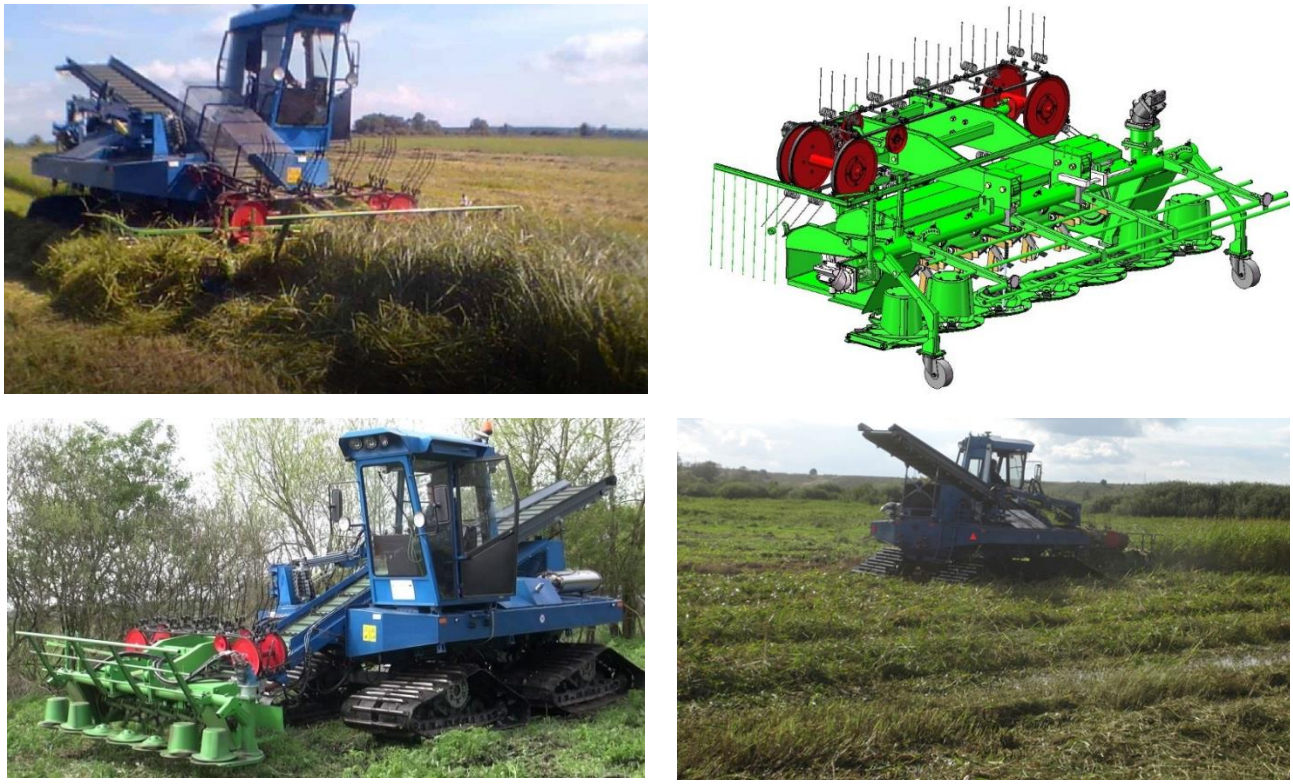

Figure 2. The front-mounted mower unit for cutting and conditioning biomass and forming swath. Top left: the disk mower with finger-wheel rake and tedder before upgrading. Top right: virtual model of the new mower unit with biomass conditioner designed by PIMR. Bottom left: real model of the new mower unit built by PIMR. Bottom right: the new mower unit during field testing on the wetlands at Biala village, where the delta tracks did not cause any damage to the top root layer of the plants. Photos: PIMR archive.

press (Figure 3) (Patent PL 228850 (2015); awards: gold medal at Brussels Eureka! 2015; winner of R&D category in XVIII Polish Future Product Competition 2015) (PARP 2016).

The whole layer of swath is picked up from the stubble, then moved over the tractor body into the feeding hopper by a scraper conveyor mounted at the bottom of the hopper. Biomass is cyclically moved into the chamber of the round bale press. Round biomass bales (diameter 1.2 m) are deposited on the ground for later removal.

Figure 3. The tracked vehicle units designed by PIMR for non-stop swath collecting and forming bales. Photo: PIMR archive.

BIOMASS TRAIN TECHNOLOGY

The biomass train technology developed by PIMR is an innovative approach for transporting biomass to temporary storage locations at the field margin. The system is based on special adapters that are used to assemble round bales into a 'biomass train' and tow them, rolling on the ground, behind a vehicle such as an agricultural tractor with wheels, a medium-sized truck or pickup equipped with delta track modules, or a 4 × 4 wheeled truck (Dubowski *et al.* 2012, Dubowski *et al.* 2013, Dubowski *et al.* 2014b). Since 2014, a new all-terrain vehicle (ATV) has been under test as a mini tractor for the biomass train.

The Prowler 700HDX wheeled side-by-side ATV

In 2014, funds from the R&D project were utilised to purchase the Prowler 700HDX, manufactured by Arctic Cat, Canada (Zembrowski 2013). After preliminary traction tests in the field, it was rebuilt into the tracked ATV and mini tractor by installing light rubber tracks and a rigid cabin. In addition, the aluminum frame of a stand to carry the adapters for the biomass bales was mounted on the floor of the vehicle's load box (Figure 4). The clevis pin hitch was constructed by PIMR. A load cell was mounted on its main beam in order to measure the towing forces (Dubowski *et al.* 2016). The tracked Prowler with adapters and tools can be easily transported on a trailer hitched to a car such as the Mitsubishi L200 or Subaru Outback.

Figure 4. Prowler 700HDX rebuilt into a tracked mini tractor for biomass trains. Note the (red) mud shoes hanging on back of cab. Photo: PIMR archive.

Prowler ATV field tests (winter)

In February 2015, the preliminary short field tests of the Prowler were conducted on the Notec River meadow at Byszewice. The primary purpose of these tests was to verify the possibility of using the light off-road vehicle as a mini tractor for transporting adapters, forming a biomass train and towing biomass bales. The safety and feasibility of mounting a new version of the folding frame adapter on biomass bales was also checked.

The field trials were carried out on a sunny day with air temperature a few degrees above freezing, when the meadow had thawed to a depth of 1–2 cm. Shaded ground was covered with frost, and shallow pools of water were frozen. Difficulties arose because the biomass bales had been left in the meadow for too long (September to February) so they were partly dried out and deformed at the point of contact with the ground (Figure 5). Indeed, they were firmly frozen to the ground, and every bale had to be mobilised by manually pushing it.

The process of drilling a steel axle into each bale using a cordless drill (BS 18 LTX-X3 Quick; Metabo, Nürtingen, Germany) did not cause major problems (Figure 5). After adding new-version steel driveshafts to the axle and laying the foldable frame of the new adapter on the driveshafts, the frame easily unfolded (Figure 5) and locked in the operating position.

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Figure 5. The trials of the biomass train in February 2015. Left: a biomass bale that had become deformed during six months' storage in the open air; such bales could still be rolled for more than 1 km in a biomass train. Below left: drilling a steel axle into a biomass bale. Below right: mounting the adapter frame on the steel axle. Second bottom: a biomass train consisting of the Prowler and five biomass bales. All photos: PIMR archive. Bottom: Google Earth satellite image displaying routes covered by biomass trains on the Byszewice trial area, recorded by VIDEO VBOX (Racelogic, Buckingham, UK).

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When the biomass bales were rolled towards the Prowler and the drawbar of the leading adapter was coupled with the clevis pin hitch, the Prowler became the shortest unit of the biomass train. It should be emphasised that the height above ground of the clevis pin hitch (0.6 m) should be equal to the radius of the towed bales so that, when the biomass train is moving, the frame adapters are arranged horizontally and oscillate around a horizontal plane (Figure 5).

Recorded routes of the biomass train towed by the Prowler are shown on a Google Earth satellite image in Figure 5. These field trials confirmed the ability of the Prowler to work as a mini tractor for the biomass train. During the tests, 14 biomass bales were transported from the field to the edge of the road. The Prowler was able to tow 2–3 bales using the drive on two tracks, and 4–5 bales with 4 × 4 drive.

The load cell readings during towing tests for increasing numbers of biomass bales (Figure 6) illustrate well the pulsating nature of the force on the clevis pin hitch of the Prowler. This reflects both the method of drilling steel axles into the bodies of the biomass bales and deformations of their cylindrical surfaces. At a speed of approximately 4 km per hour, the towing force for a five-bale biomass train ranged from 2 kN to 4 kN.

On the basis of these field trials, it can be concluded that using the Prowler as a mini tractor will enable transport of the foldable adapter frames, assembly of the biomass train, and rolling of up to five biomass bales (diameter 1.2 m) on muddy terrain. Employing a light all-terrain vehicle provides an opportunity to both significantly reduce the cost of transporting biomass bales on wetlands and improve environmental protection. Due to the traction advantages of the lightweight tracked off-road vehicle, the fuel consumption of the Prowler engine (15 kW, 700 cc) is significantly lower than that of the larger motors (70–90 kW) used in conventional agricultural tractors.

Prowler ATV field tests (autumn)

In October 2015, the attempts to tow 1.2 m diameter biomass bales were repeated, this time on the Notec River flood polder near Biala (Figure 7). In contrast to the situation in February, the cylindrical surfaces of the bales did not show substantial deformations because they had only recently been made using PIMR's latest method of non-stop biomass swath collecting, discussed above.

For a biomass train consisting of a Prowler and five biomass bales, the towing forces measured were in the range 2.5–4.5 kN (Figure 7). The force acting on the clevis pin hitch again showed pulsations,

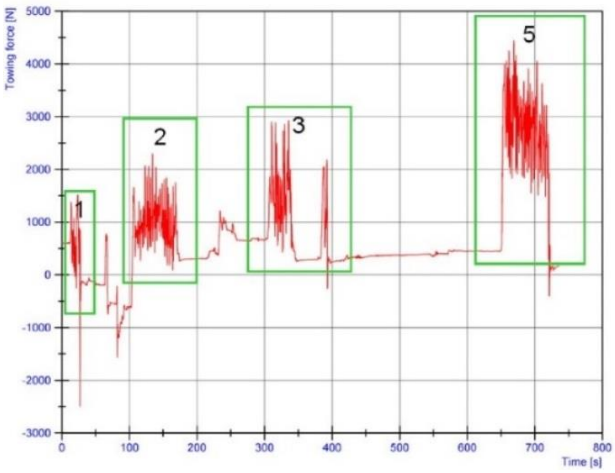

Figure 6. Towing forces for 1, 2, 3 and 5 biomass bales measured during the biomass train field trials at the Byszewice site (NI 2012).

which is to be expected for a method involving setting up adapters on individual biomass bales and towing them over uneven grassy terrain. These results were only slightly higher than those previously obtained in the Byszewice field tests. They increased because the grassy terrain was more deformable than the frozen meadow and, therefore, presented a slightly higher rolling resistance when towing bales. Also, at the point of departure from the meadow, there was a slight incline up to the road separating the meadow from the farmyard, and the final part of the journey (225–300 s) was in an unpaved yard.

During these field trials it became clear that a significant reduction in the weight of the adapter is required, because moving multiple relatively heavy (52 kg) adapters is too strenuous for the workers. A 52 kg adapter is cumbersome when carried manually on a firm surface, and carrying it becomes inconvenient and unsafe when walking on boggy terrain wearing mud shoes (spikeless snowshoes; see Figure 4). The development of much lighter (15–20 kg) adapters will allow a more complete assessment of the functionality, safety, durability and service life of the vehicle.

Suitability of the tracked ATV for wetlands work

The pilot tests of the use of a light off-road vehicle as a means of carrying transport adapters, forming a train of biomass bales and towing them from the wetland to a storage location on a farm matched up to the expectations of the PIMR research team. The off-road vehicle selected was a multi-purpose model which served not only as a technical support vehicle but also as a tracked mini tractor with ability to tow

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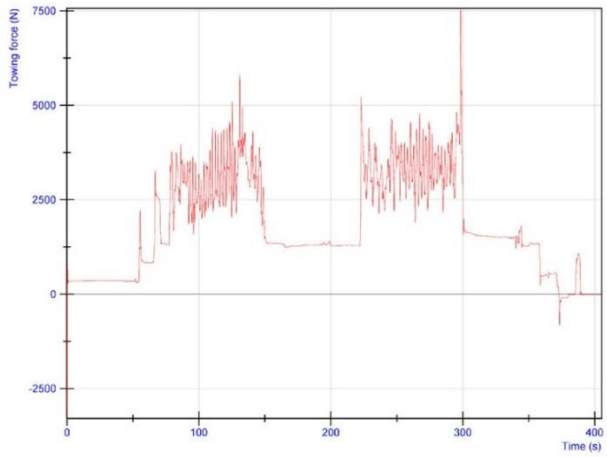

Figure 7. Above: the Prowler being used as a mini tractor for the biomass train in the field trials near Biala in October 2015. Photo: PIMR archive. Left: The forces on the clevis pin hitch when towing five biomass bales during the October 2015 field trials (NI 2012).

biomass bales using 4 × 4 drive and low-gear automatic transmission. The Prowler's rigid cabin reliably protected the driver and measuring equipment from the effects of different weather conditions (rain, dust, wind, sun) and insects (mosquitos, flies). The stand for the foldable frames of the adapters, mounted on the load box floor, proved to be a durable and fully functional design solution. The forces measured on the Prowler's clevis pin hitch during towing indicated the possibility and reinforced the need to reduce the weight of the adapters.

Because the water table fell significantly during the drought of 2015, the usually very muddy test meadows were dry with fairly good load-carrying capacity during the field trials, in principle allowing access not only by all tracked vehicles but also by our passenger trucks and cars (Mitsubishi L200, Iveco and Subaru Outback); although the wheels of the Iveco got stuck in the mud on one occasion when it was towing a gooseneck trailer. Thus, there is potential and a need for further research on innovative vehicles for use in the T-PT, as well as on other machinery and tools designed by PIMR as parts of the integrated technology for removing biomass from areas with low bearing capacity such as marshy terrain.

The tests of transporting biomass bales demonstrated the real effectiveness and efficiency of the method. The data obtained will allow potential producers and customers to assess the exceptional advantages of this innovative method for transporting biomass bales over the environmentally harmful use of tracked trailers towed by modified snow groomers for this purpose, or the dangerous procedure of transporting individual bales on the fork lift of a wheeled agricultural tractor. It seems that light tracked off-road vehicles (e.g. the Prowler) should be adopted for the transport of biomass bales, alongside wheeled trucks and wheeled agricultural tractors. Implementation of the biomass train technology should bring about a technological revolution which will promote protection of the environment, and especially of wetlands in National Parks that are being managed as breeding areas for endangered bird species.

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KEY POINTS

- The tracked vehicles designed and developed by PIMR are much better able to move on wetlands than adapted snow groomers (ratracs) or wheeled tractors, and cause minimal damage to the peatland surface.

- The hydraulic systems of PIMR's vehicles use biodegradable oils and thus avert the risk of serious pollution in the case of spillage as result of accidents or breakdowns.

- The front-mounted mower unit for cutting and conditioning biomass to form swath works well, and when the swath is cut into ~ 30 cm pieces it can be more easily shaped into rows and subsequently collected from the ground using the non-stop collection method.

- The tracked vehicle unit for non-stop swath collection and formation of round bales is able to do the work without any stops for forming the bales and pushing them out of the press chamber. Fuel consumption is reduced because the engine is working under optimal conditions of constant speed, and also because the work can be completed in a shorter time.

- Bales left in the wetlands can be transported according to the biomass train technology using tracked or wheeled agricultural tractors, tracked ATVs and even light off-road cars. Using vehicles with smaller engines (light wheeled tractors, ATVs, off-road cars and light trucks) is much more efficient and, therefore, less costly than using heavier tractors with higher fuel consumption. Smaller vehicles and wheeled tractors are able to tow 5–6 round bales at 4–6 km h^{-1} on muddy ground. Using the Prowler 700HDX ATV (bale diameter 1.2 m) or a wheeled tractor (bale diameter 1.6 m), the towing forces of the biomass train are in the range 2.5–6.0 kN.

- No effects on the ground or damage to vegetation were observed during the field testing of biomass trains, in contrast to the deep ruts and damage to the top root layer caused by tracked ratracs coupled with tracked trailers, or by wheeled tractors transporting bales on the front loader. We expect that, in the near future, the biomass train will be capable of rolling 16–20 round biomass bales (diameter 1.6 m) over the ground simultaneously.

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