17TH INTERNATIONAL RAMIRAN CONFERENCE
"Sustainable utilisation of manures and residue resources in agriculture"
4-6 September 2017 – Clayton Whites Hotel, Wexford, Ireland

Optimisation of maize stover harvesting chain for biogas production

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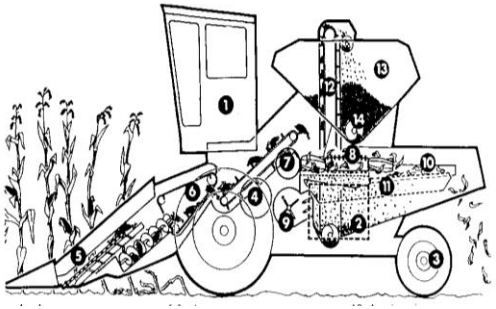
Main Agricultural and Animal Farming Residues for biogas production in **Italy**

	Potential availability (kt DM/year)
Animal manure	**15000**
Maize stover	**4600**
Winter cereal straws	**2400**
Rice straw	**650**

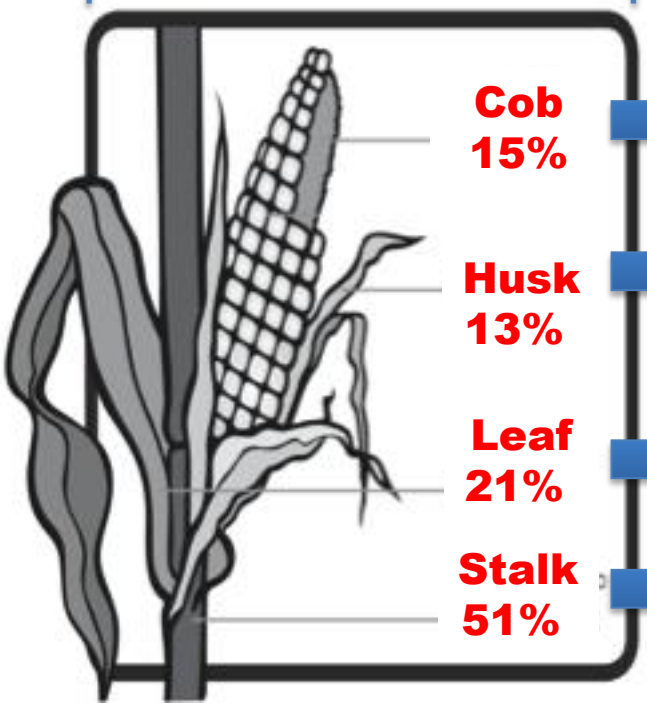
Elaborated by DISAFA based on ENAMA (2011) and UNIVPM (2013) data

Maize stover fractions and their methane potential



Crop residue

(≈ 50% of the whole maize plant)



POTENTIAL METHANE YIELD

($Nm^3CH_4\ Mg^{-1}SV$)

Cob 15%	206
Husk 13%	307
Leaf 21%	245
Stalk 51%	234

(Menardo et al., 2015)

Main constraints to the use of maize crop residue for biogas production

- **High moisture content (> 40-45%)**
- **Commonly left in the field after harvesting the grains**
  - → soil contamination
  - → up to 20% biomass losses depending on climate and operative conditions at the time of collection
- **Lacking of specialized harvesting chains**
  - → High energetic and economic costs

proper biomass harvest and temporary storage chains are needed

Objective of the study

developing and testing of three different harvesting chains (HC) for grain harvesting and stover collection in one single passage

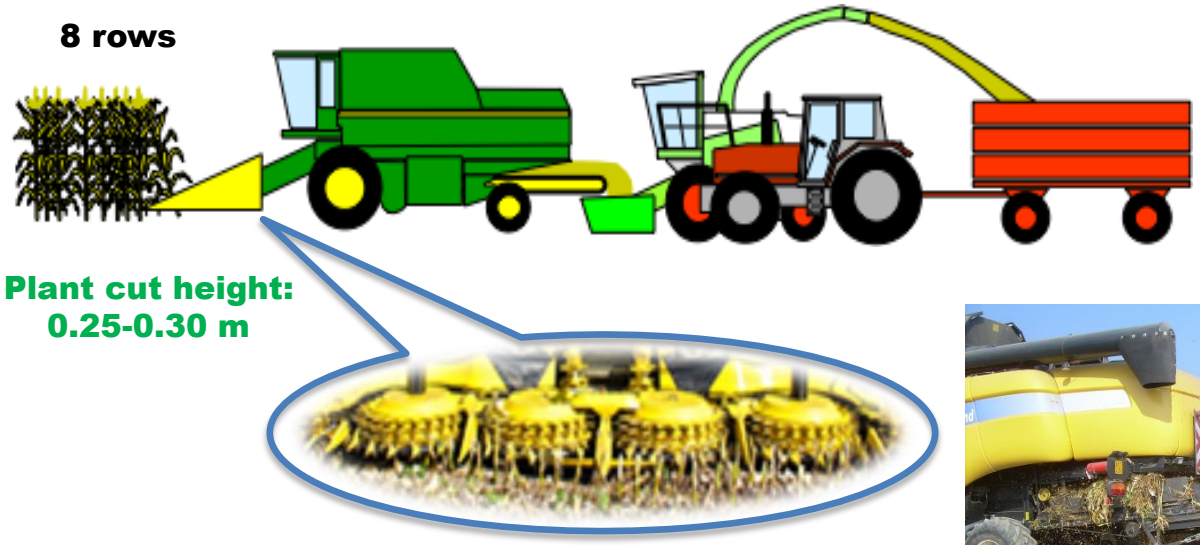
- Avoiding contact of biomass with soil

- Wet storage by ensiling technique

- Energetic valorization of maize stover in anaerobic digestion plants

Maize stover harvesting chains description

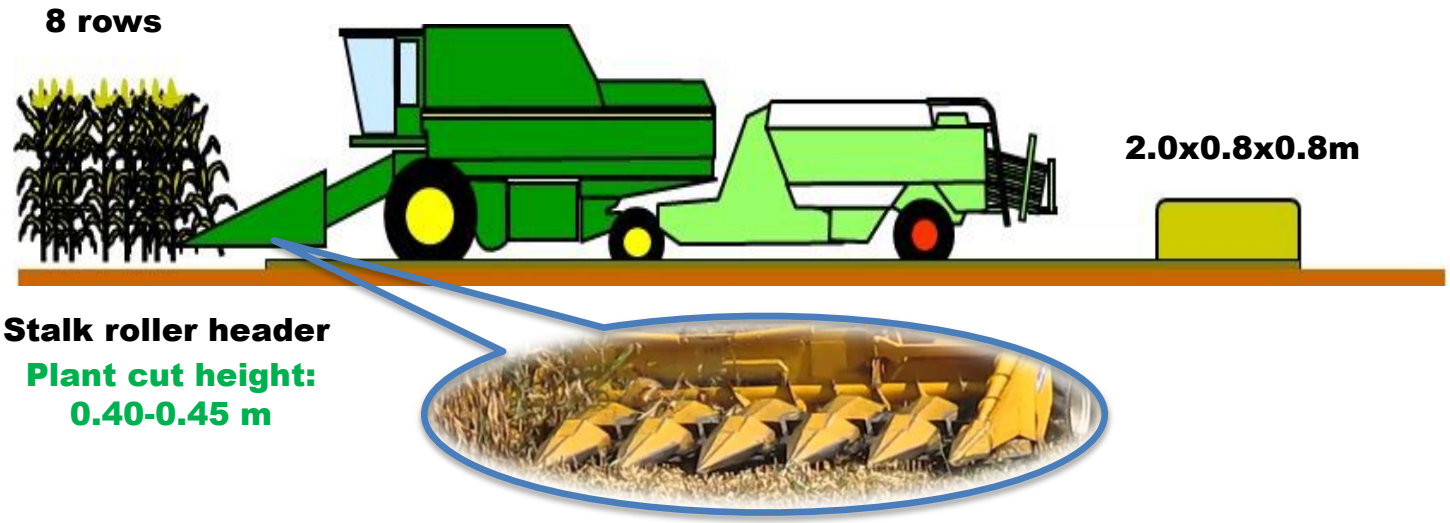
- **Chain 1: harvesting of the whole maize plant, chopping of the biomass residue and its storage into a concrete bunker silo**



Operation	Machinery used	Storage structures and materials
Collection	Self-propelled combine, 265 kW; shredder loader 198 kW; Tractor, 92 kW + 30 m^3 trailer	
Transport	Tractor, 92 kW + 30 m^3 trailer	
Storage (Ensiling)	Tractor, 88 kW	Concrete pavement + precast concrete walls; low density polyethylene film
Utilization (daily feeding of the digester)	Tractor with front loader, 88 kW	

Maize stover harvesting chains description

- **Chain 2**: partial harvest of stover (i.e., mainly leaves, cobs and husks), biomass ensiled in square wrapped bales



Operation	Machinery used	Storage structures and materials
Collection	Self-propelled combine, 265 kW + baler	
Transport	Tractor with front loader, 74 kW + 24 m^3 trailer	
Storage (Ensiling)	Wrapping machine + Tractor 92 kW	Low density polyethylene film; precast concrete walls
Utilization (daily feeding of the digester)	Tractor with front loader 74 kW + Ensiled stover cutter + Tractor 92 kW	

Maize stover harvesting chains description

- **Chain 3**: partial harvest of stover (i.e., mainly leaves, cobs and husks), chopping of the biomass residue and its storage into a concrete bunker silo

Operation	Machinery used	Storage structures and materials
Collection	Self-propelled combine, 265 kW; shredder loader 198 kW; Tractor, 92 kW + 30 m^3 trailer	
Transport	Tractor, 92 kW + 30 m^3 trailer	
Storage (Ensiling)	Tractor, 88 kW	Concrete pavement + precast concrete walls; low density polyethylene film
Utilization (daily feeding of the digester)	Tractor with front loader, 88 kW	

Materials and Methods

➢ Field Trials description

- ✓ Irrigated maize crop (hybrid class: FAO 600; seed density: 7.5 plants m^{-2}) field in Turin province (Northwest Italy)
- ✓ Three homogeneous areas of 1.5ha (150x100m) each
- ✓ 700 m average distance from the field to the biogas plant
- ✓ Biomass storage by ensiling for a 60 days period

ASSESSED PARAMETERS PER EACH TESTED MAIZE STOVER HARVEST CHAIN

a) Field capacity (ha h^{-1}, MgDM h^{-1})

- ASABE Standard indications (ASABE, 2011)

b) Energy requirements (INPUT)

- Directs –> energy content of fuel (51.2 MJ kg^{-1}) and lubrificants (52.9 MJ kg^{-1})
- Indirects –> machine and equipment energy (MJ kg^{-1})

c) Energy obtained through anaerobic digestion (OUTPUT)

- Biochemical methane potential (BMP) of harvested biomass → lab-scale batch trials (VDI 4630, 2006)

Results

- *Field capacity of investigated harvesting chains and average chemical composition (n=3) of collected maize stover*

Chain	Collected biomass	Field capacity		Main chemical composition of collected biomass				
				DM (%)	VS (%DM)	NDF (%DM)	ADF (%DM)	ADL (%DM)
	MgDM ha^{-1}	ha h^{-1}	MgDM h^{-1}					
1	9.8	1.3	12.4	44.9b	94.7b	77.0b	43.6a	6.2a
2	2.5	1.6	3.9	62.8a	96.8a	84.4a	41.7b	5.0b
3	2.4	1.6	3.8	62.0a	97.0a	83.4a	39.4b	5.2b

Values followed by the same letter are not statistically different using Tukey's test at 5% level

Results

- *Specific methane yield and energetic potential of investigated biomasses*

Harvest chain	Specific CH_4 yield	Gross energy yield	Potential Energy (*)	
			Electrical	Thermal
	l_N kgVS^{-1}	GJ ha^{-1}	MWh ha^{-1}	MWh ha^{-1}
1	252.1[b]	93.1	10.9	12.9
2	272.0[a]	26.2	3.1	3.6
3	274.9[a]	25.5	3.0	3.5

Values followed by the same letter are not statistically different using Tukey's test at 5% level

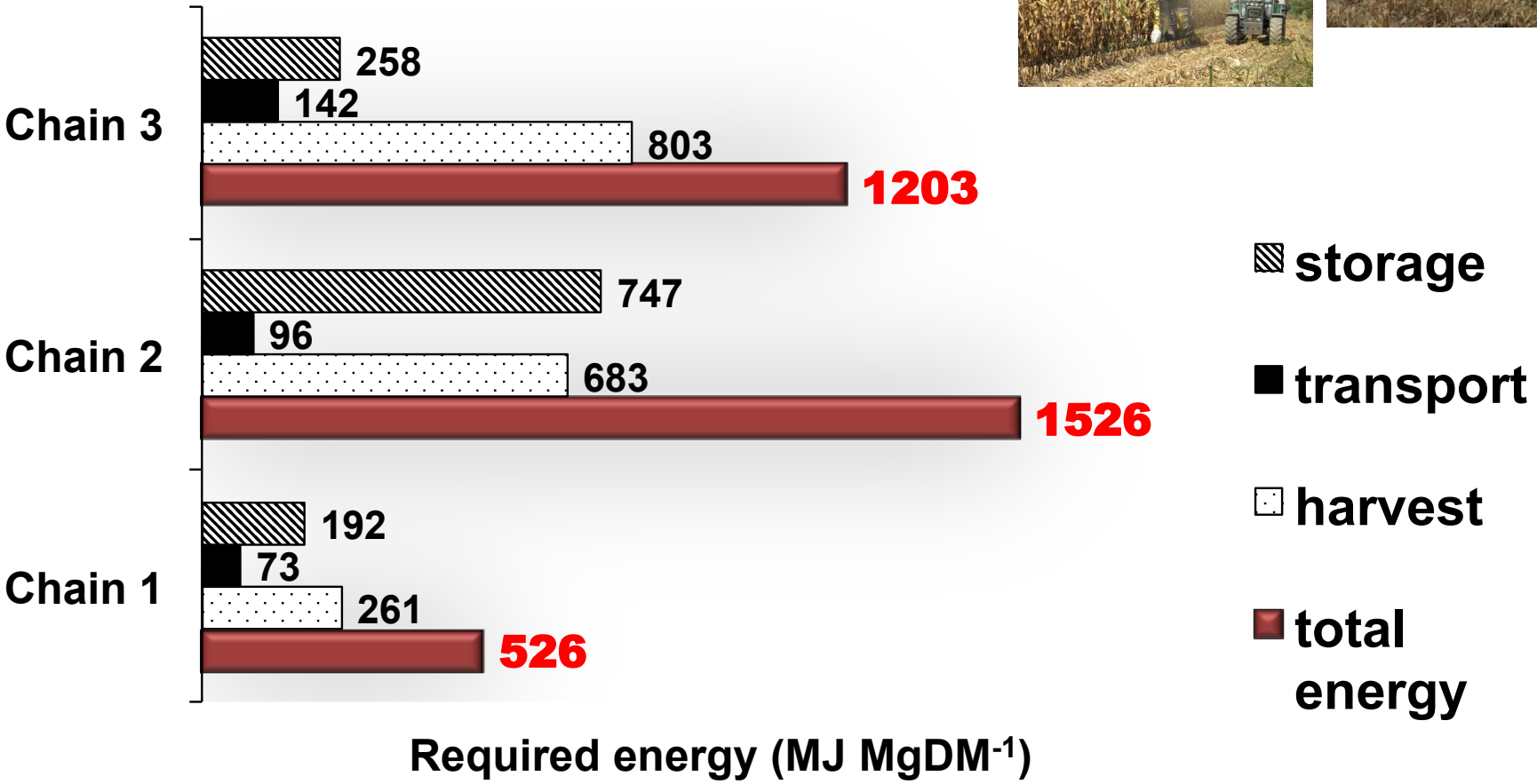
(*) Values obtained assuming :

-) higher heating value of CH_4 = 39.8 MJ l^{-1}

-) a CH_4-fuelled CHP electrical and thermal efficiency of 42% and 50%, respectively

Results

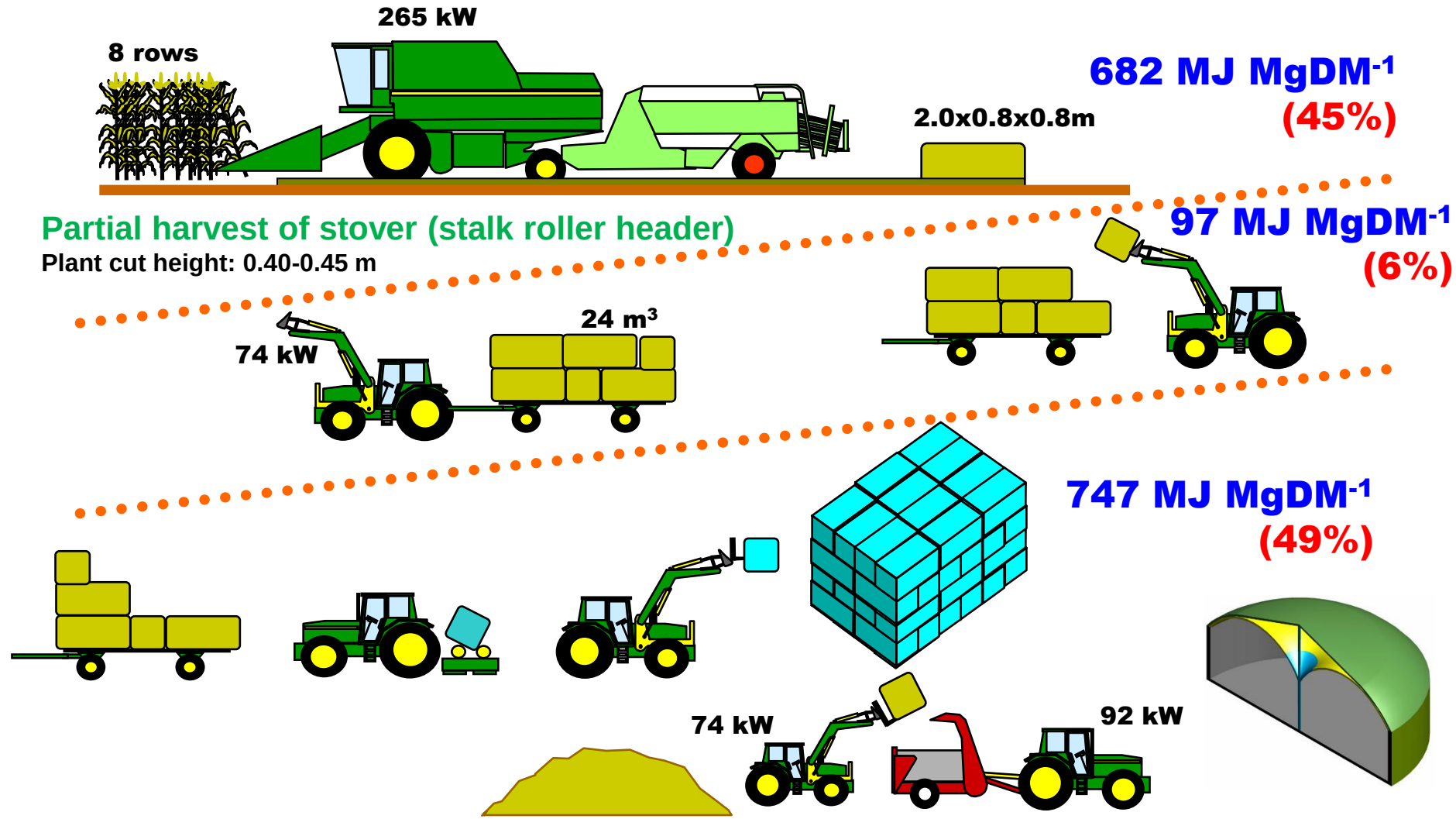
➢ Energy requirements



Results

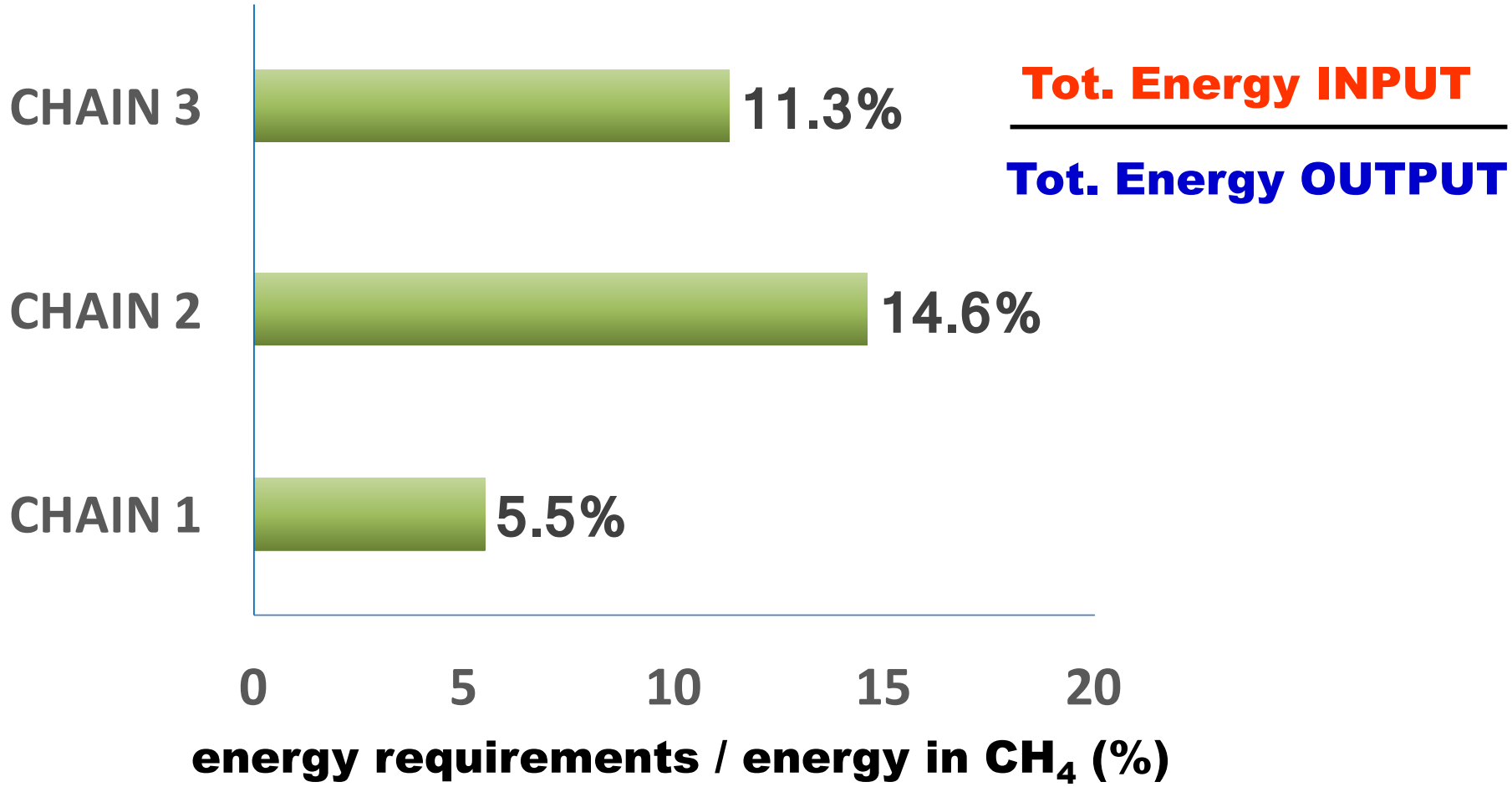
➢ Energy requirements: Chain 2

☞ **Total energetic costs: 1526 MJ $MgDM^{-1}$**



Results

- ***Energy balance of tested harvest chains***



CONCLUSIONS

- **Good energetic performances of all investigated harvesting chains (energy input:output ratio < 15%)**

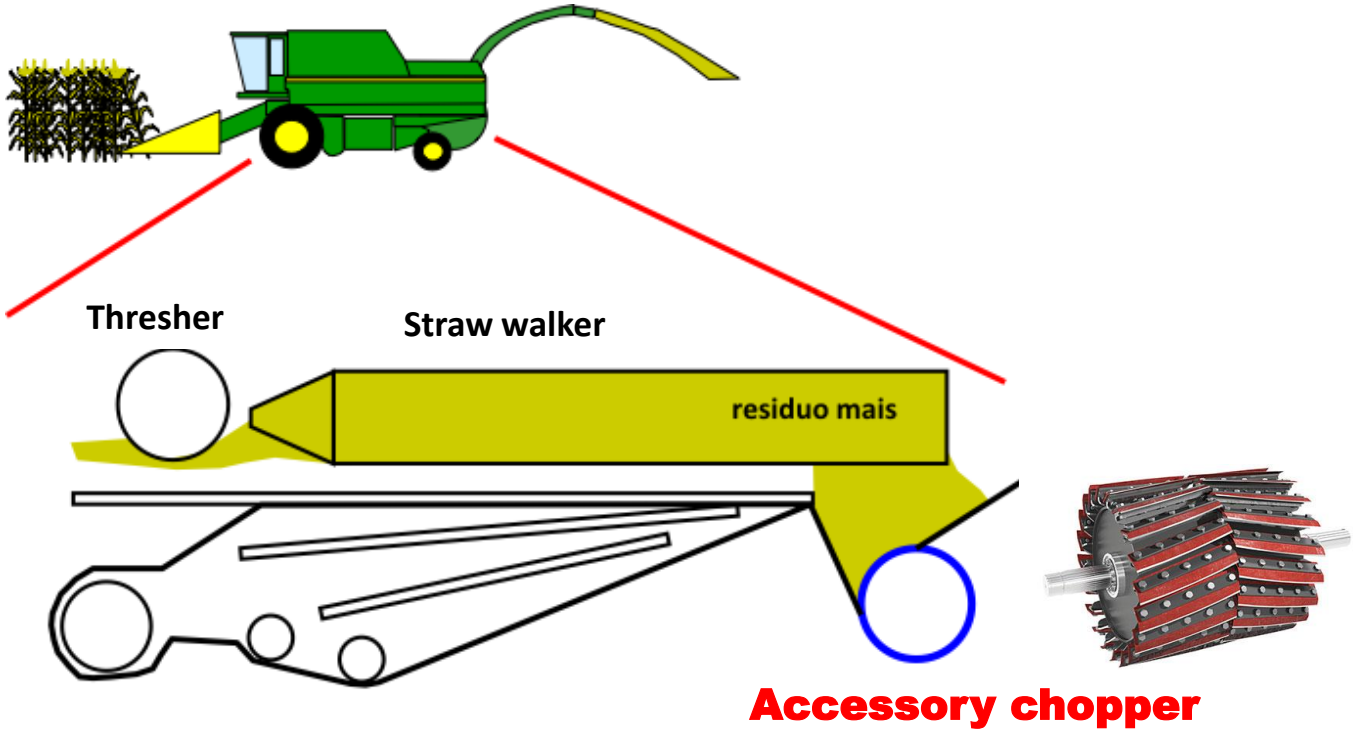
- **Chain 1 was the most efficient chain among those analysed, nevertheless:**

☞ Notable reduction of combine field capacity

☞ High incidence of biomass harvest (50%) operations on total energy requirements

☞ improving maize stover harvest efficiency

Self-propelled combine equipped with a device to chop the material leaving sieves and straw walker









Thank you for your attention

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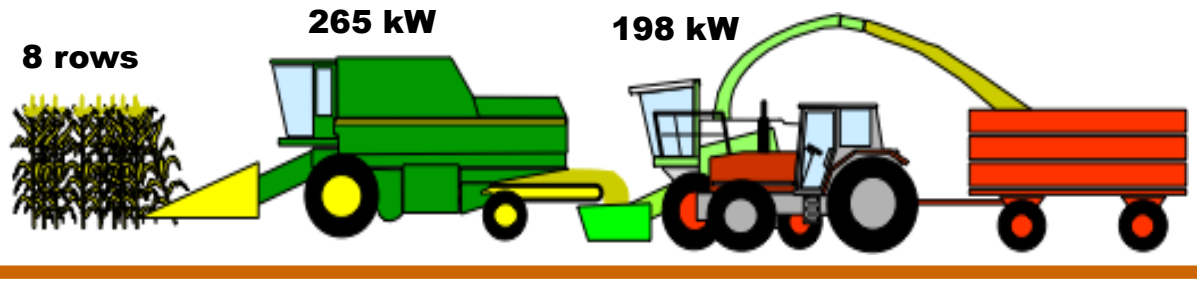
Results

➢ Energy requirements: Chain 1

Total energetic costs: 526 MJ $MgDM^{-1}$

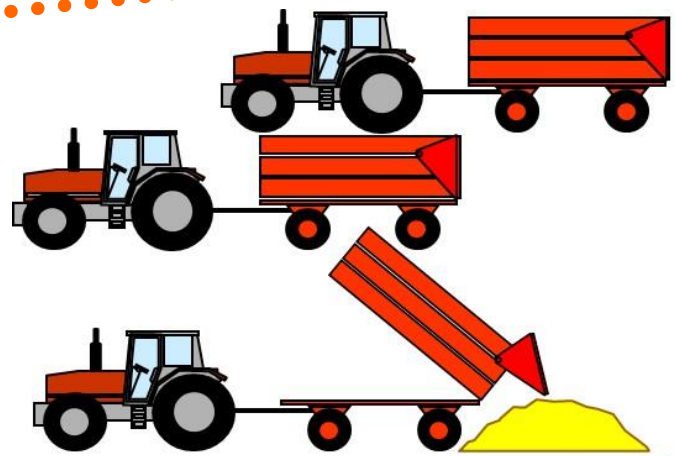


261 MJ $MgDM^{-1}$ (50%)

Harvesting of the whole plant

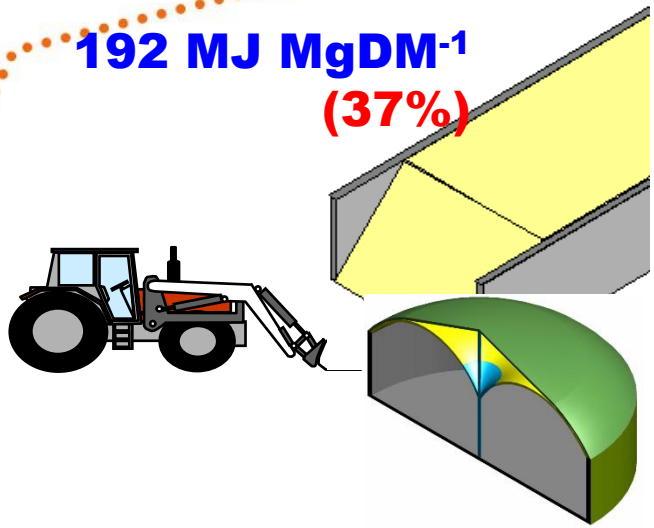
Plant cut height: 0.25-0.30 m

73 MJ $MgDM^{-1}$ (14%)



- Distance 0.7 km
  - 2 trailers

192 MJ $MgDM^{-1}$ (37%)



Results

➢ Energy requirements: Chain 3

Total energetic costs: 1203 MJ $MgDM^{-1}$

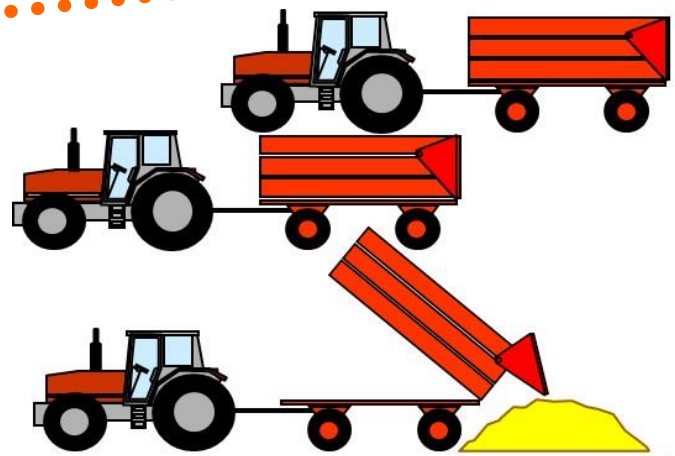
803 MJ $MgDM^{-1}$ (67%)

Partial harvest of stover (stalk roller header)

Plant cut height: 0.40-0.45 m

142 MJ $MgDM^{-1}$ (12%)

- **Distance 0.7 km**
  - **2 trailers**



258 MJ $MgDM^{-1}$ (21%)