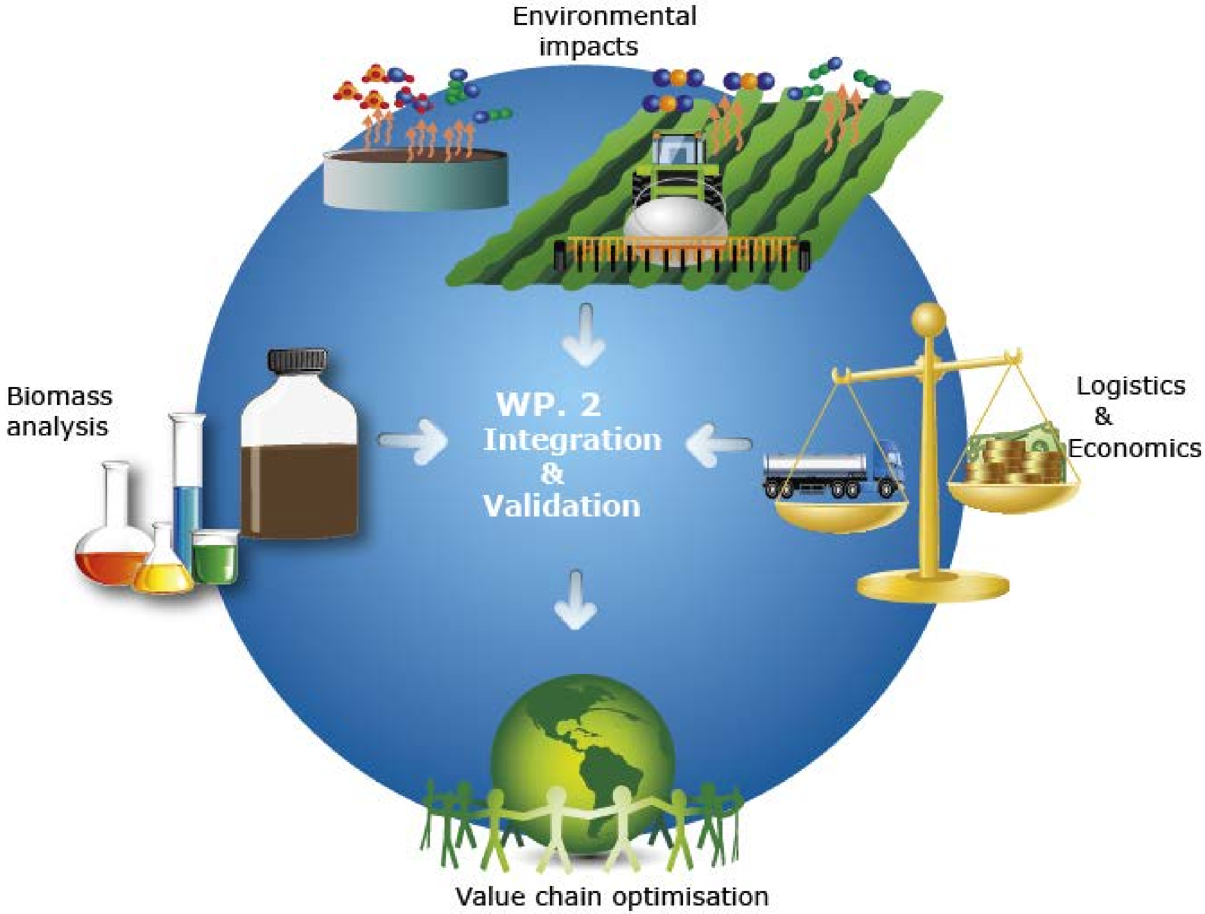
Work package 2
Integration and validation of models



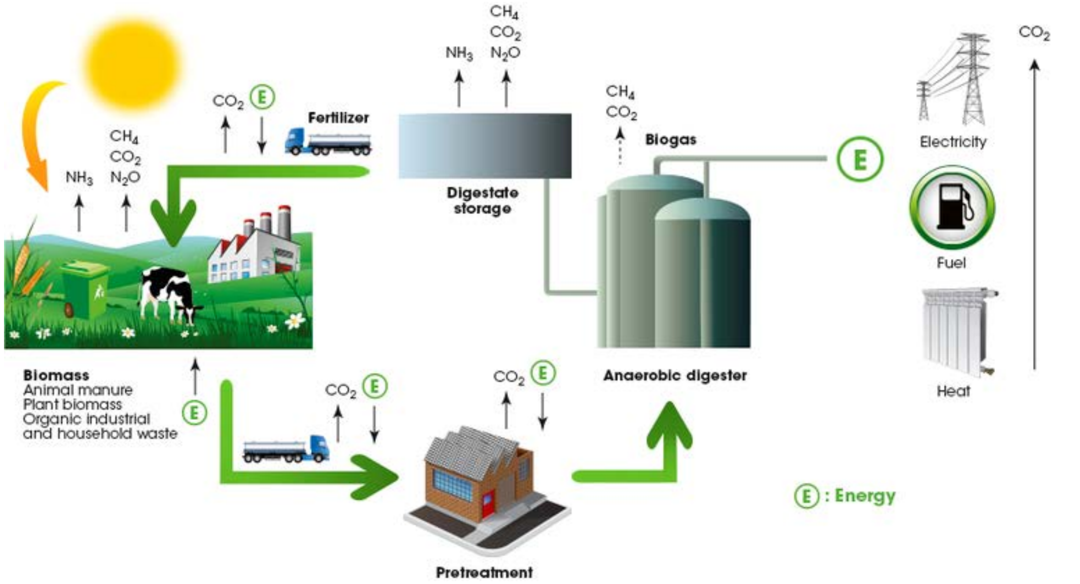
OBJECTIVE AND RESULT

Objective

Develop model integrating **value** chain and **biogas** and **environmental** models.

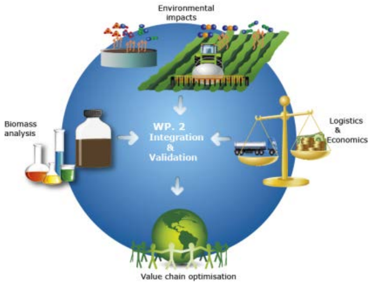
Result

Decision support for biogas plant management and regional/national decision making.

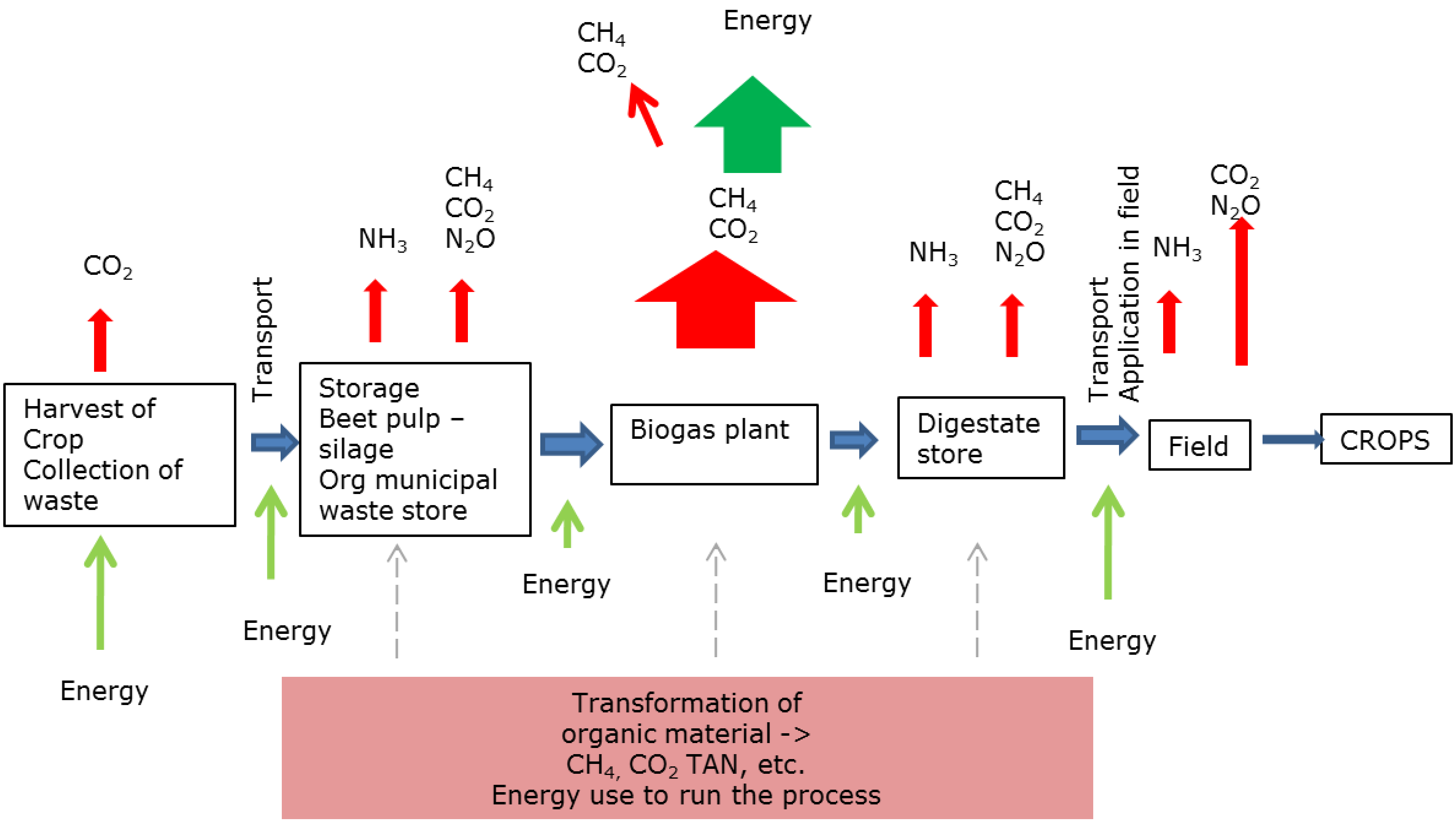


Deliveries (D) and Milestones (M)

- **D: Spreadsheet conceptual model** (December 2013)
- **M: Integrated model**
  - Dynamic model – assessing a system with management of sugarbeets and household waste. 2014 (Workshop January 2014).
  - Include algorithm that reduce need for definition of biomass but use real-time data from new analytical instrument. 2015&2016.
- **M: Collect data from two biogas plants** (2014 & 2015)
- **D: Final decision support model** (2016)
- **D: Models validated** (2016)



Example of Conceptual excel model



Examples of concept model work

Biogas production of sugar beet in Energy production and Greenhouse Gas Reduction

Harvest in October
- Beet top for animal feed
- Beet root for bigas production

Harvest ↓

Dry Cleaning in the field
- Removing soil, sand, stones, etc.

Cleaning ↓

Ensilage for 8 months
- Whole beet root, fermentation
- Covered

Ensilage ↓

Cattle manure →

Co-digestion with cattle manure
1200m3, 6ton/day, 37°C, HRT 20days

Biogas production ↓

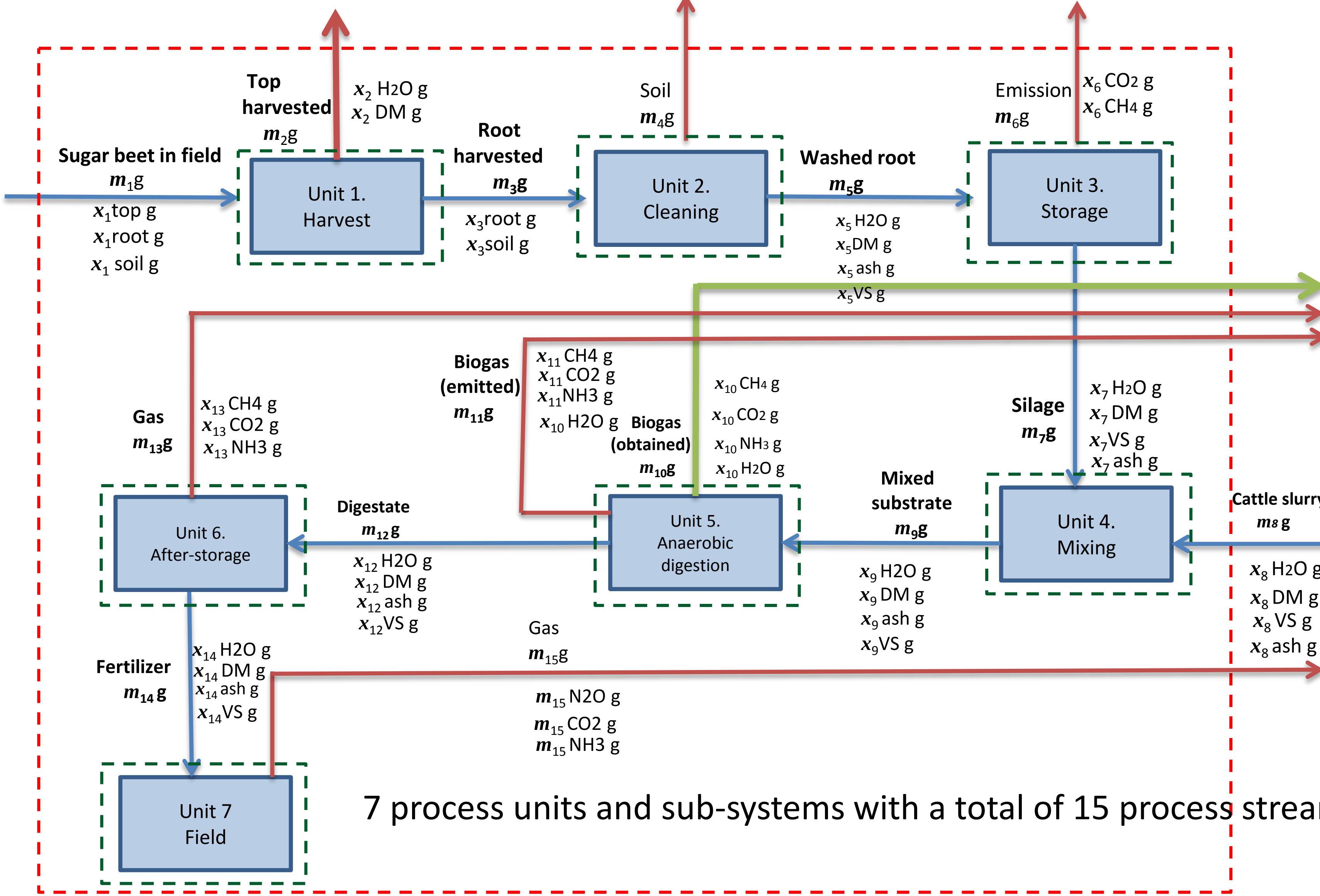
PVC roof (avoid dilution), until field application

Post -storage ↓

Applied in October or April

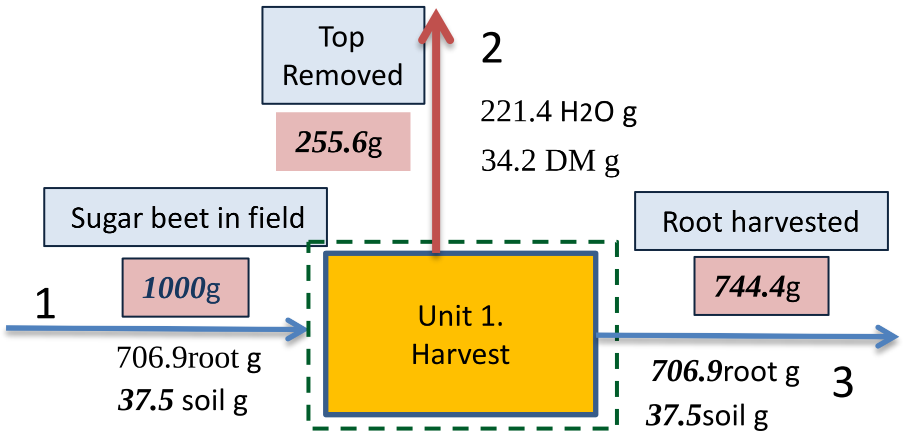
Field

Flow chart of Reference Scenario



7 process units and sub-systems with a total of 15 process streams

Process unit 1. Harvest

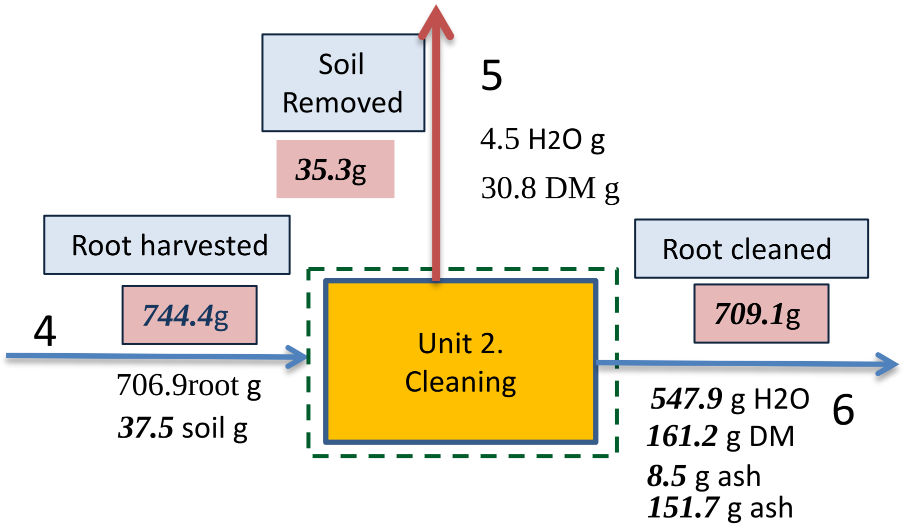


- Top for animal feed
- Root for biogas production
- Soil : 22% of beet's dry matter

Composition of root +soil (stream 3)

- Total 744.4g
  - Dry matter 192.0g
    - VS 152.7g
      - VSED 138.3g
        - VSED Carbohydrate 129.8 g
        - VSED Lipid 0.8g
        - VSED Protein 7.8g
      - VSND 14.4g
    - Ash 39.3g
  - Water 552.4g

Process unit 2. Cleaning



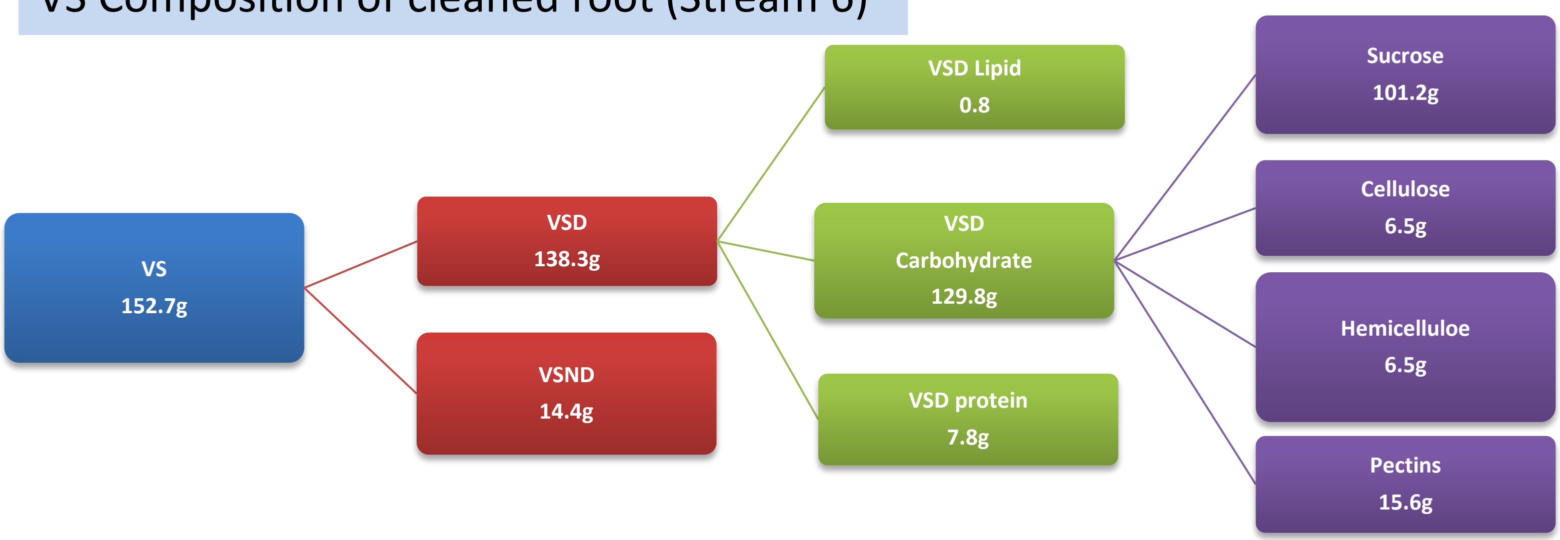
Cleaned root

AgroTech (Jørgen Pedersen)

Soil residue

- 3.4% (dry cleaning)
- 2.1% (wet washing)

VS Composition of cleaned root (Stream 6)



Process unit 3. Ensilage

- GHG emission
  - CH_4 emission during first period (2-3 weeks)
  - 1.2 CH_4L/kg beet =2.5% of BMP (Agrotech)

- VS change
  - German study (Weißbach *et al.*, 2009) :16%
  - Our study : 27.4(2.0%)

- German study (Weißbach et al., 2011)

Beet type	BMP (L/kg VS)	BMP (L per kg fresh beet)
Fresh beet	361	83
SIlage	383	81

- BMP change
  - Increasing of BMP per VS
  - Slight decreasing of BMP per total wet weight

- Our study

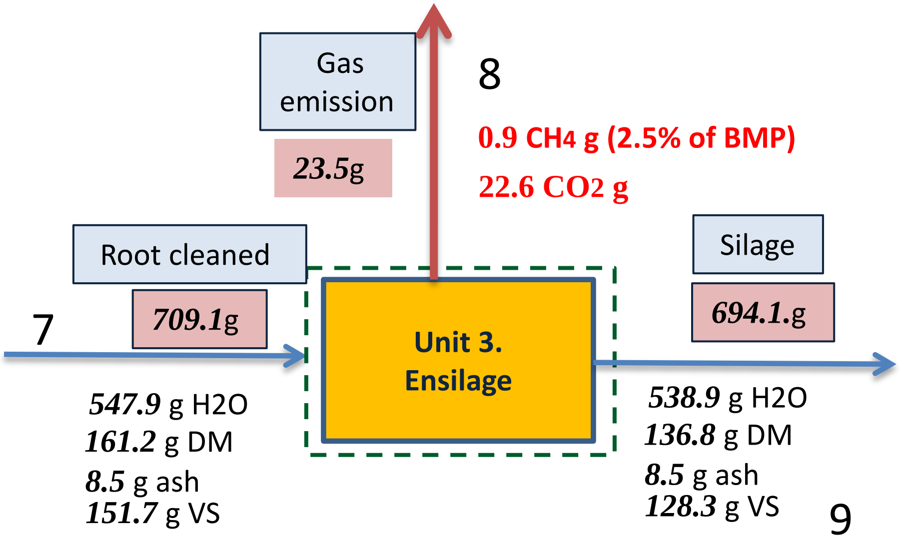
Beet type	BMP (L/kg VS)	BMP (L per kg fresh beet)
Fresh beet	324	70
Silage	359	67

- TBMP of sucrose and ethanol

	TBMP per kg VS		Before Ensilage	After ensilage
	CH_4 NL kg VS^{-1}	CO_2 NL kg VS^{-1}	g	g
Sucrose	**393**	393	101	31
Ethanol	**730**	244	0	21

Process unit 3. Ensilage

Mass balance flow chart of Ensilage



- **Well fermented root silage**

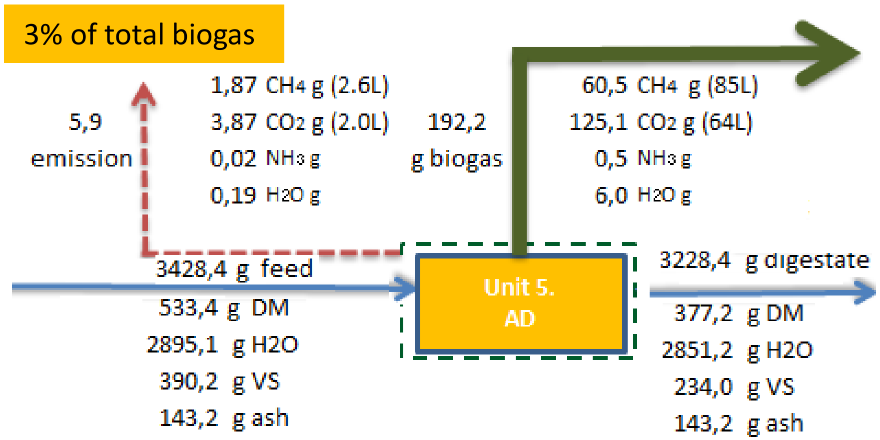
AgroTech (Jørgen Pedersen)

- VS destruction : Great dependency of ensilage duration

		Fraction (%)	
	Before ensilage	Up to 6 months	More than 6 months
Sucrose	78	60	30
Glucose	0	6	8
Ethanol	0	10	20
Hexoses	5	7	9
Pentose	5	7	9
Pectins	12	10	24
Total	100	100	

- Methane potential less affected due to alcoholisation of carbohydrate
- CO_2 gas emission from fermentation (CO_2 neutral)
- Lack of data for modelling

Process unit 5. Biogas production



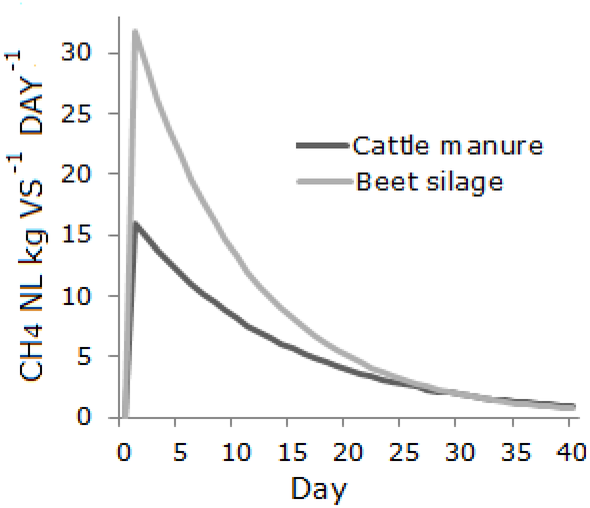
44L CH_4 from cattle manure

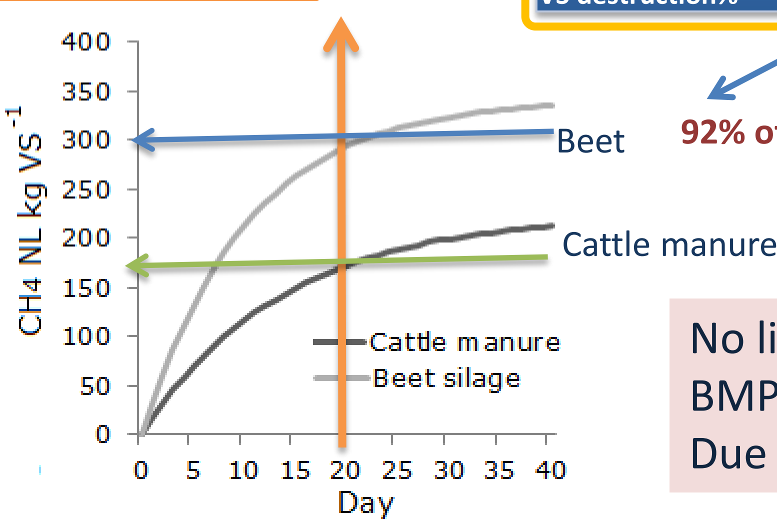
42L CH_4 From Beet root

VS destruction

	Beet	Manure
Input VS g	128	261
Removed VS g	90	66
Remaining VS g	39	196
VS destruction%	70	25

- Methane production rate and cumulative yield



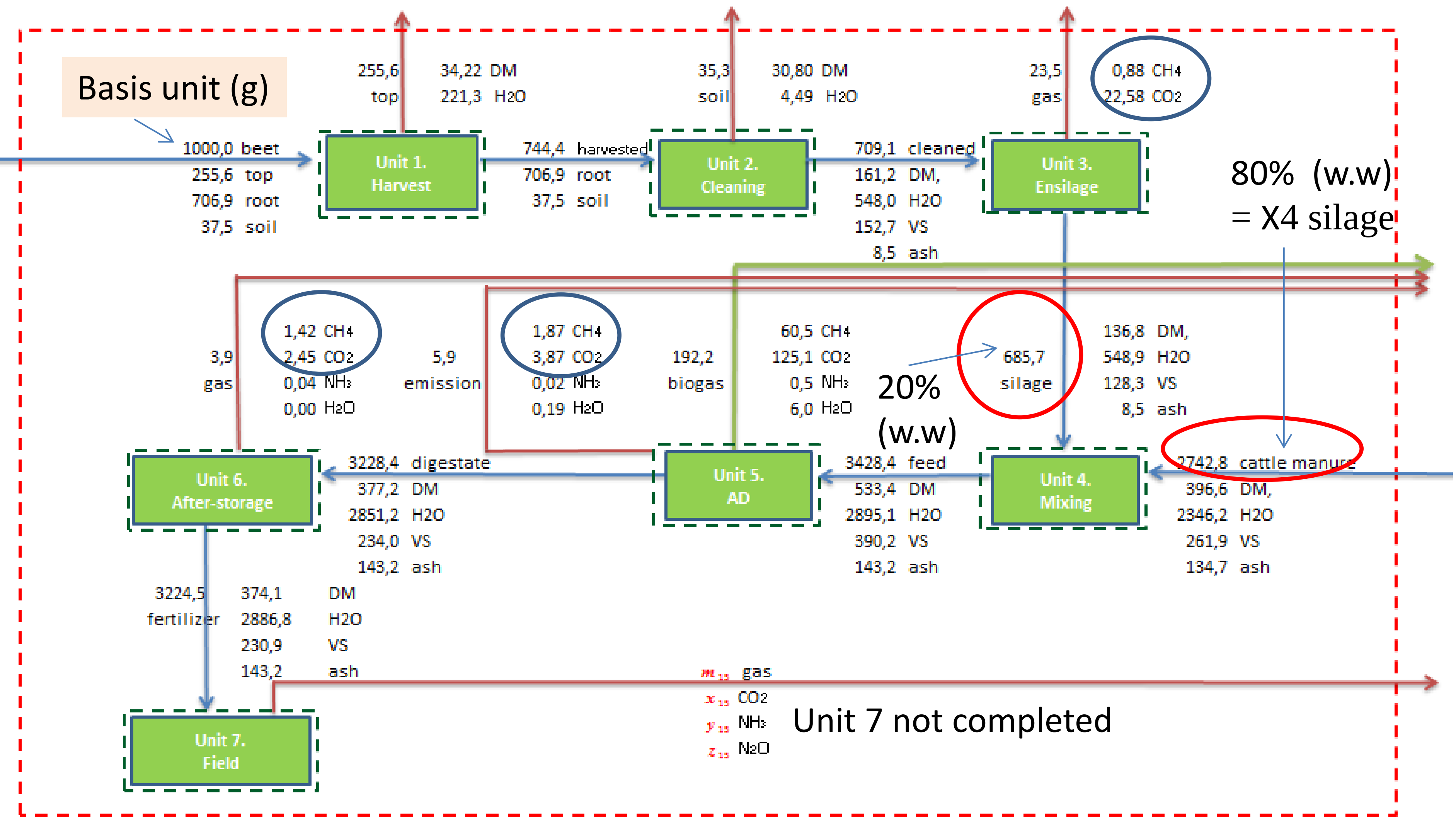


92% of BMP removed

85% of BMP removed

No linear relation between BMP and VS destruction
Due to different digestibility

Overview of model
(1000 g of beet + 2700 g cattle manure)



Scaling up model (Annual beet harvested ton per ha)

Scaling

- Changing values of all amounts or flow rates by proportional amount.
- Compositions remain unchanged.

Scale factor = Desired basis / Reference basis

$$\frac{123\text{ton ha}^{-1}\text{ yr}^{-1}}{1000\text{g}}$$

0.123 (ton ha^{-1} yr^{-1} g^{-1})

Basis of reference model (1000g beet)

X (S.F)0.123 (ton ha^{-1} yr^{-1} g^{-1})
S.F multiplying flow rate of all the stream (not fraction)

Basis of up-scaled model = 0.123 (ton ha^{-1} yr^{-1})

Energy production

Basic Model
(beet 1000g +2742g cattle manure)

Biogas
- CH_4 60.5g (84.7L)
- CO_2 125.1g(63.7L)
- Total: 185.6g(148.4L)

Energy
- 3.4MJ

Electricity
- 0.95Kwh

Upscaled Model
(beet harvested ton **ha**$^{-1}$ **yr**$^{-1}$ + cattle manure)

Biogas
- CH_4 : 8.4.Mg (11780 m3)
- CO_2 : 17.4Mg (8855 m3)
- Total: 25.4Mg (20634m3)
- 43m3/ton

Energy
- 474588MJul
- 941MJ/ton

Electricity
- 131Mwh (261Kwh/ton)

GHG emission using biogas technology (Reference Model)

With Biogas production (Beet + manure)

- **CH_4 : 4.177g (0.88g ensilage, 1.87g biogas plant emission, 1.42g after-storage)**
- **CO_2 : 7.289g**
- **GHG as CO_2 eq. : 111.7 g**

Without biogas production (manure)

- **CH_4 : 4.183g , CO_2 : 7.3g , GHG as CO_2 eq. : 111.9g**

No GHG reduction, may be due to :

- **GHG emission from beet silage included**
- **CH_4 emission from ensilage**
- **Emission from a biogas plant**

Improvement of current method to determine GHG emission during storage of digestate

IPCC (2006) methodology

- CH_4 [kg] = VS [kg] * BMP[$m^3 CH_4$ per kg VS]*MCF*0.67 [kg CH_4 per m^3 CH_4]
- (*IPCC choose to use BMP of fresh slurry from animal house*)
- **1.07 CH_4 [kg]/ [kg]** = ((0.27VS [kg] *0.224[m^3 CH_4 per kg VS](BMP of fresh slurry) * 0.67[kg CH_4 per $m^3 CH_4$] * 0.1(MCF))/2.7kg

Method used for our study

- After biogas production the BMP of the digestate is quite lower than BMP of fresh slurry. BMP of digestate is applied. *Reduced BMP must be applied!*
- **0.25 CH_4 [kg]/ [kg]** = ((0.27VS [kg] *0.051[m^3 CH_4 per kg VS](BMP of fresh slurry) * 0.67[kg CH_4 per m^3 CH_4] * 0.1(MCF))/2.7kg

Risk of over estimation of GHG emission using IPCC current protocol in biogas scenario

➡ Our experiments on BMP of digestate from full scale biogas plant (7samples) (0.086 (±19) m^3 CH_4 per kg VS)

Achieved

Staff

Post Doc (From 1st November) Jin Mi Triolo have started contributing to this work in June 2013

Progress

- Agree on and an understanding of the joint work to be carried out.
- Draft manuscript: Presenting the dynamic model framework for assessing biogas and GHG emissions.
- Oral presentation of the proceeding article "Biogas from beet pulp and source separated household waste- Energy production and Greenhouse Gas Reduction. Sommer S.G., Astrup T., Boldrin A., Bruun S., Jensen L.S., Petersen S.O., Abildgaard L., Triolo J.M. Conference "Science for the Environment for society", Aarhus Univ. 3-4 October 2013.

Data from biogas-& energy companies to be used for validation

- Feed - biomass
- Management, retention time, shift in biomass, temperature, pre-treatment etc.
- Gas production (quality, volume..)
- Etc.

Gas emission from biogas plants

- Joint research activity measuring gas loss from biogas plants
- Method
  - Methane concentration measured up and downwind the biogas plant
  - Wind speed measurements at the height of gas concentration measurements
  - Assessment of gas emission using windtrax (Backward Langrangian
- Set up a data base – including data about biogas plant characterisation (Size, digestion method, feed, storage, etc.
- Write an article

Questions

- **New knowledge need**
  - BMP of digestate is not related to VS transformation during fermentation
  - BMP of biomass for digester not linear related to VS
- **End user need**
  - Outcome of the decision support tool?
  - Information for the model in general available by the end user?
- **Demand to the analytical tool**
  - Which characteristics
  - Cost (investment & running cost)