# ENERGY CROPS FOR BIOGAS

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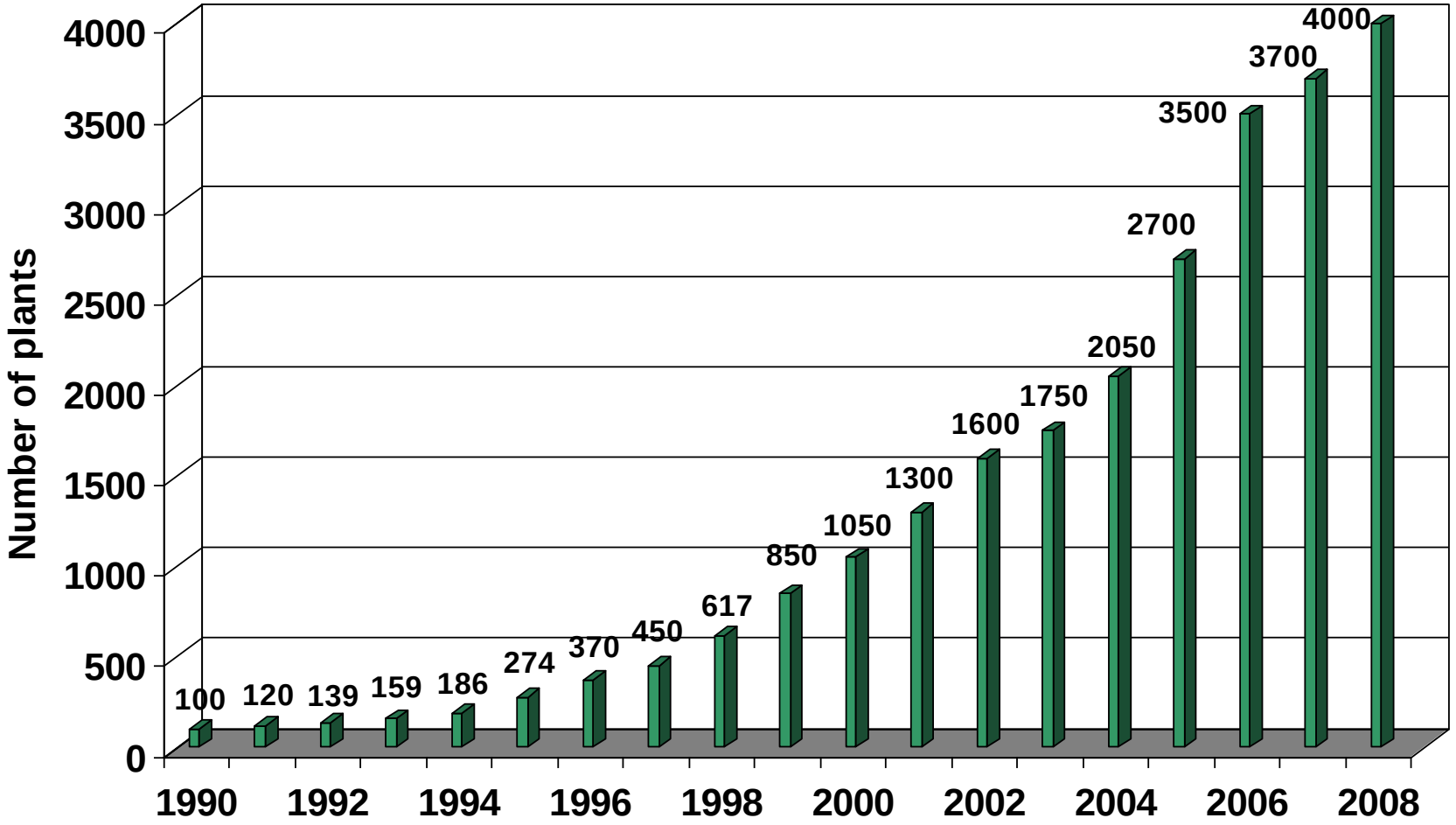
# CONTENTS

- Current status of biogas progress
- Process technology of energy crop digestion
- A representative full scale example
- Biogas plant monitoring & evaluation
- Energy balance and energy efficiency
- Economics estimation of biogas production

# Development & Status of Biogas Technology

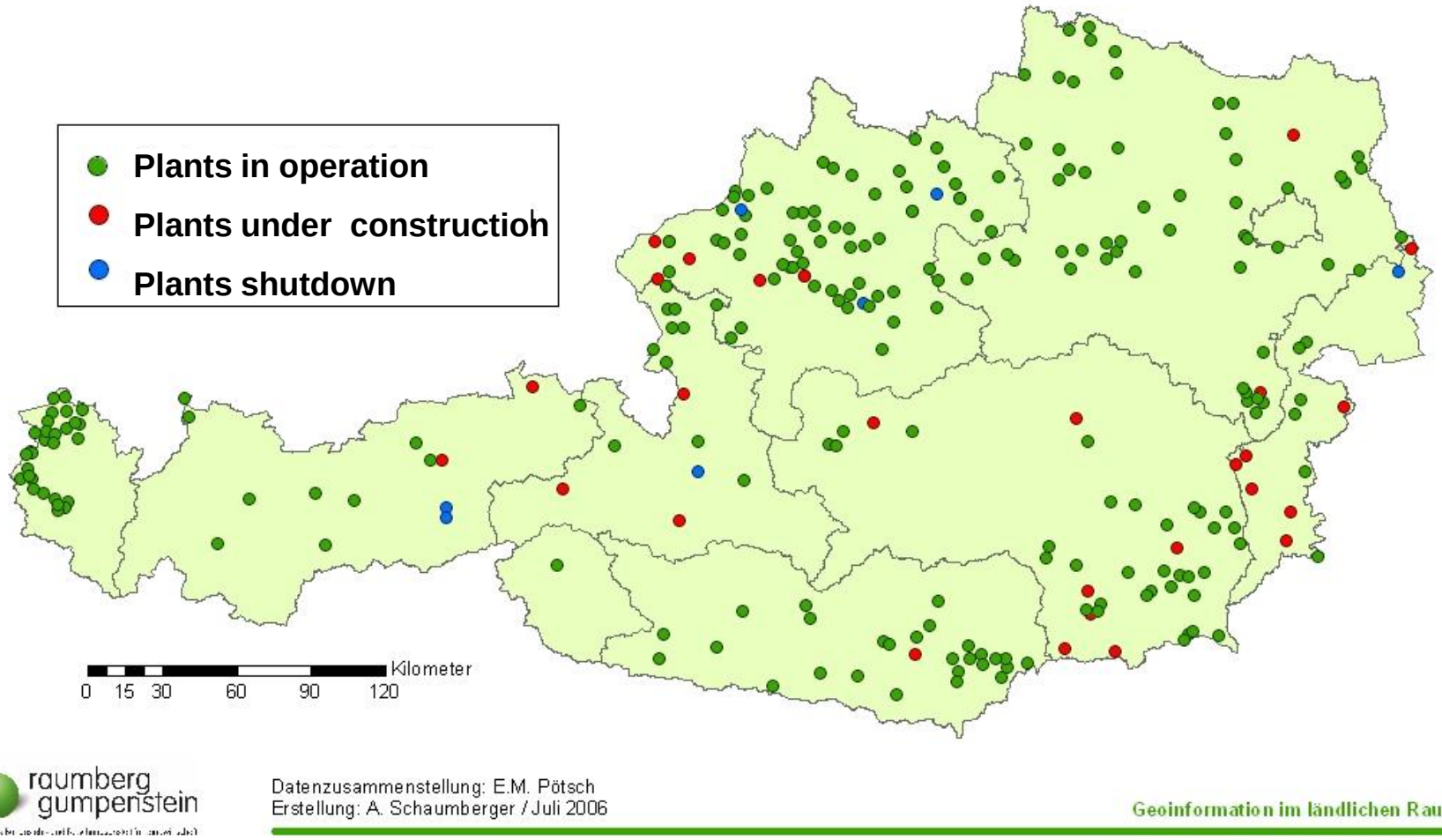
# Development of biogas technology in Germany

(after Weiland, 2009)



# Current situation in Austria

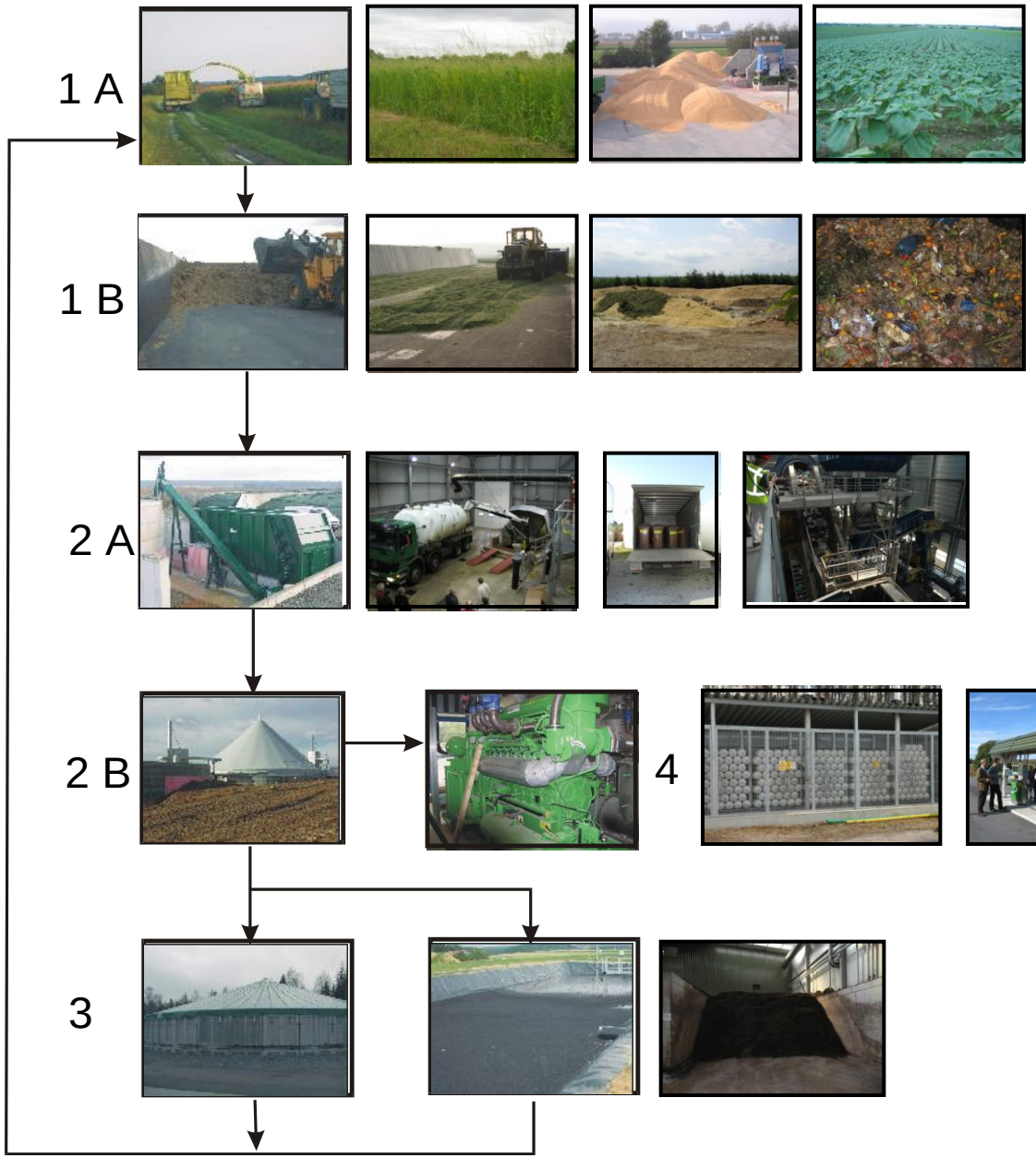
## Approximately 350 Agricultural biogas plants in Austria



# Austrian Tariffs for Green Electricity from Biogas

| | BGBL II 508/2002 | BGBl II 401/2006 | BGBl II 401/2007 | BGBl II 59/2008 | BGBl I 114/2008 |
|---|---|---|---|---|---|
| | 2002-2004 | 2006 | 2007 | 2008 | 2008 |
| | [ Cent/kWh ] | [ Cent/kWh ] | [ Cent/kWh ] | [ Cent/kWh ] | [ Cent/kWh ] |
| ≤100 kW | 16,50 | 17,00 | 16,95 | 16,94 | + 4,00 |
| >100 - 250 kW | 14,50 | 15,20 | 15,15 | 15,14 | + 4,00 |
| >250 - 500 kW | 12,50 | 14,10 | 14,00 | 13,99 | + 4,00 |
| >500 kW - 1MW | 12,50 | 12,60 | 12,40 | 12,39 | + 4,00 |
| >1 MW | 10,30 | 11,50 | 11,30 | 11,29 | + 4,00 |
| Landfill Gas | 6,00 | 4,10 | 4,05 | 4,04 | |
| Gas WWTP | 3,00 | 6,00 | 5,95 | 5,94 | |
| min. Utilization | | 60% | 60% | 60% | |
| Co-Substrates | -25% | -30% | -30% | -30% | |
| Limit | | | 30% of € 17 Mio/a | | |
| Guarantee | 13 Year | 10 Year<br>Year 11: 75%<br>Year 12: 50%<br>Year 13-24: Market Price | 10 Year<br>Year 11: 75%<br>Year 12: 50%<br>Year 13-24: Market Price | 15 Year | 2008 only |

# Technology of Energy Crop Digestion




Renewable raw materials (Crops)

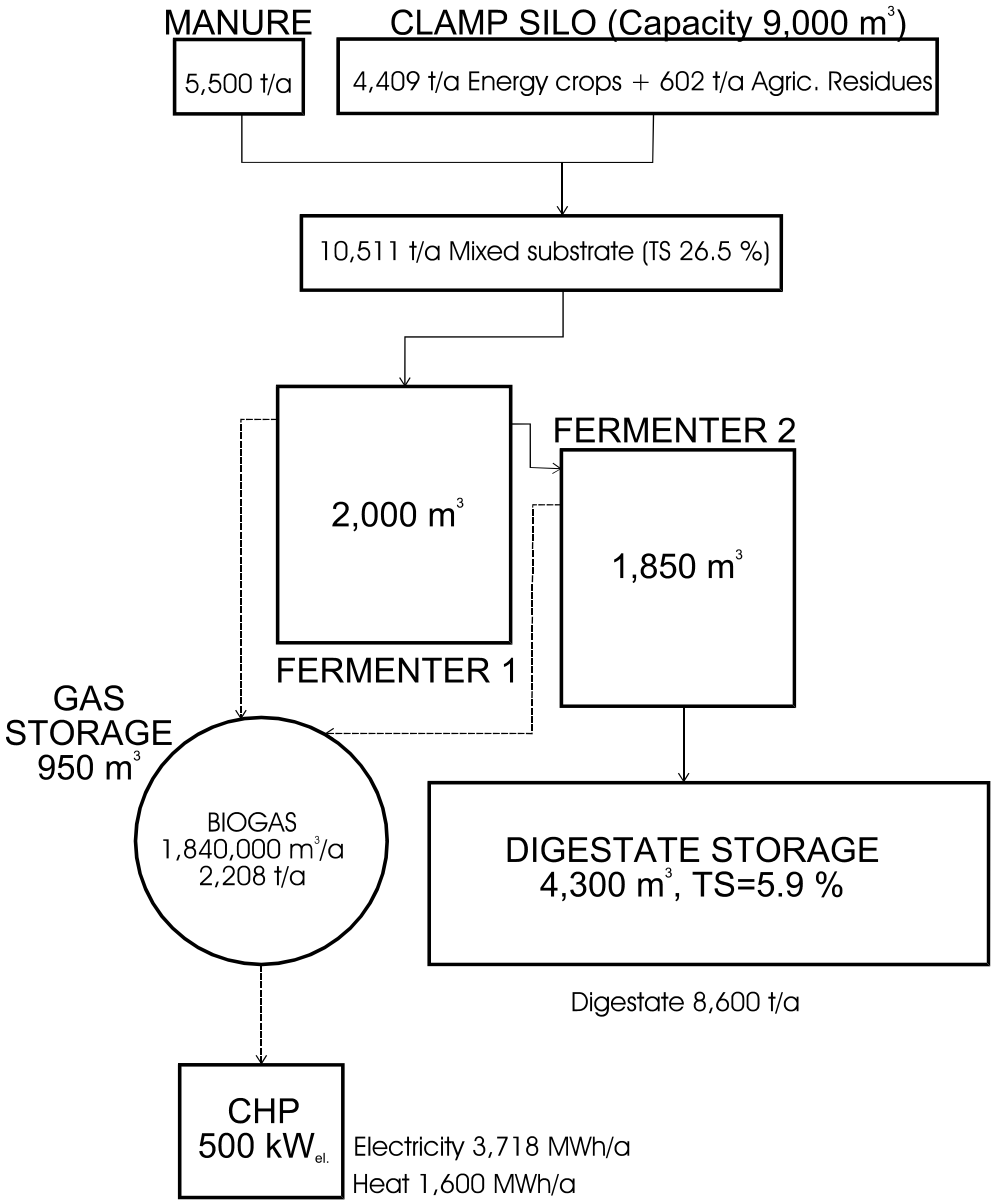
Bio-waste, by-products

Substrate preparation & dosage into digesters

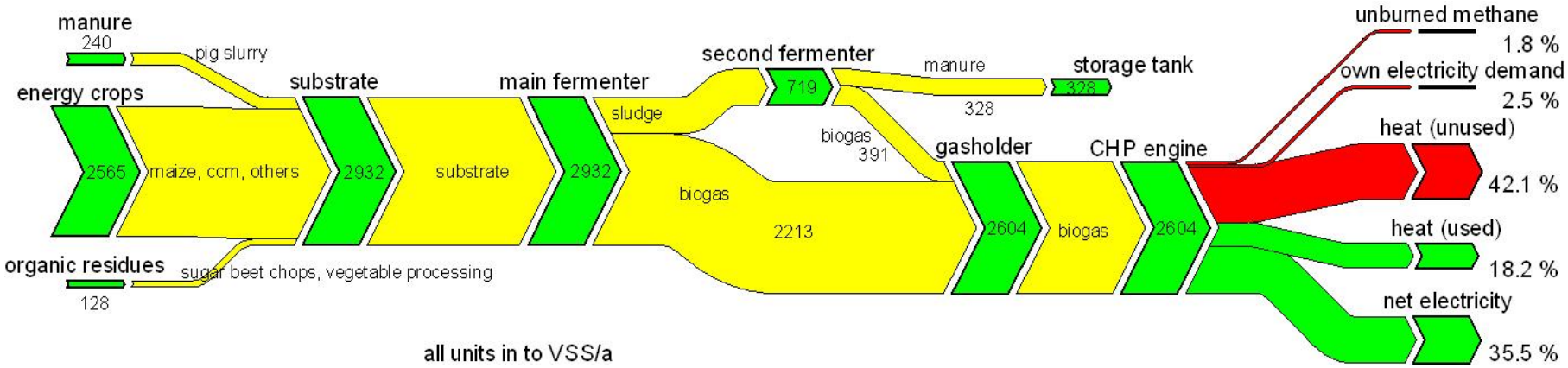
Biogas use for power generation and /or upgrading to fuel

Use of digestate as fertilzer and/or compost

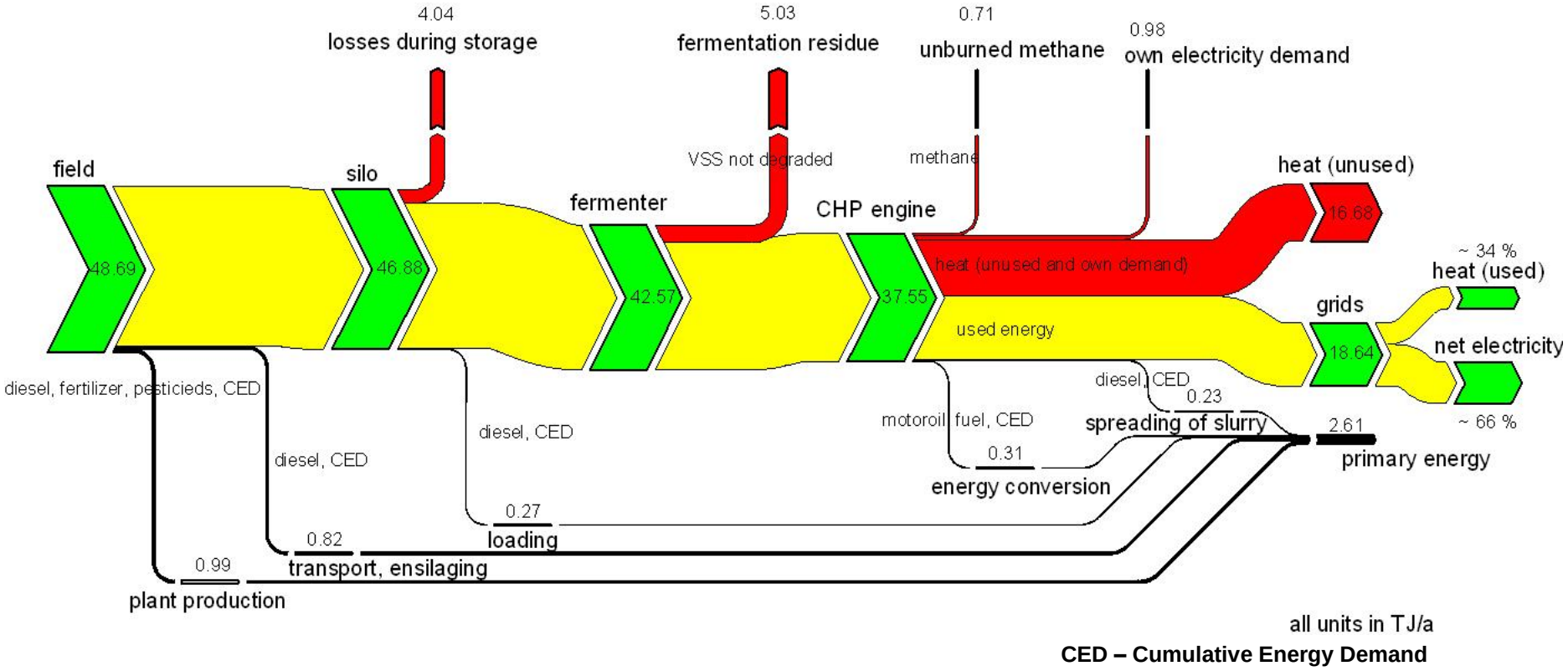
# Representative example of an 500 $kW_{el.}$ „Energy Crop“ Co-digestion plant


MANURE
5,500 t/a
CLAMP SILO (Capacity 9,000 m³)
4,409 t/a Energy crops + 602 t/a Agric. Residues
10,511 t/a Mixed substrate (TS 26.5 %)
2,000 m³
FERMENTER 1
FERMENTER 2
1,850 m³
GAS STORAGE 950 m³
BIOGAS 1,840,000 m³/a 2,208 t/a
DIGESTATE STORAGE 4,300 m³, TS=5.9 %
Digestate 8,600 t/a
CHP 500 kW el.
Electricity 3,718 MWh/a
Heat 1,600 MWh/a

# Mass flow (VS) during energy crop production-, digestion- and energy use



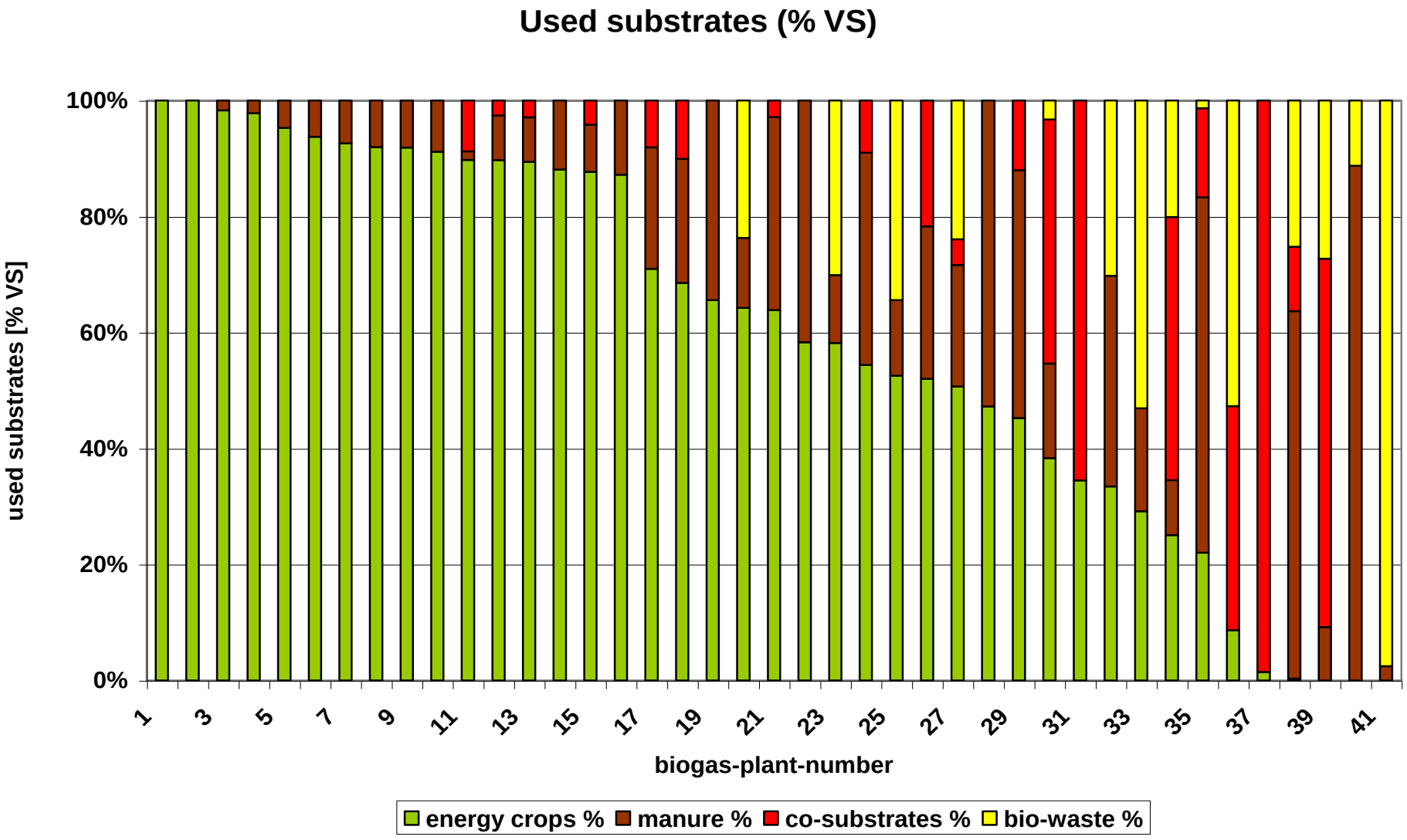
# Energy flow during energy crop production-, digestion- and energy use



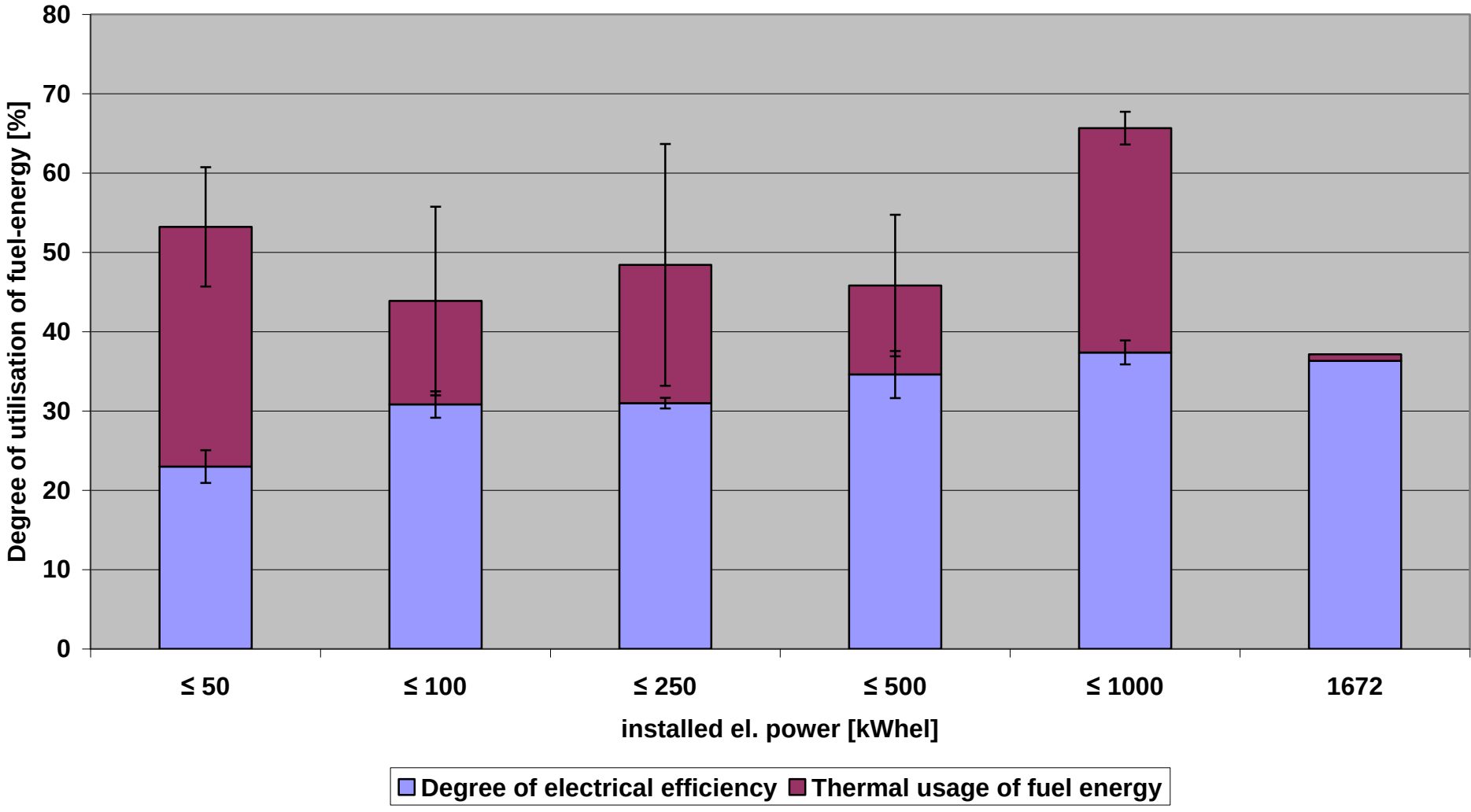
# Biogas plant monitoring & evaluation

**<u>2004 – 2006</u>: 23 % of all existing Austrian biogas plants investigated**

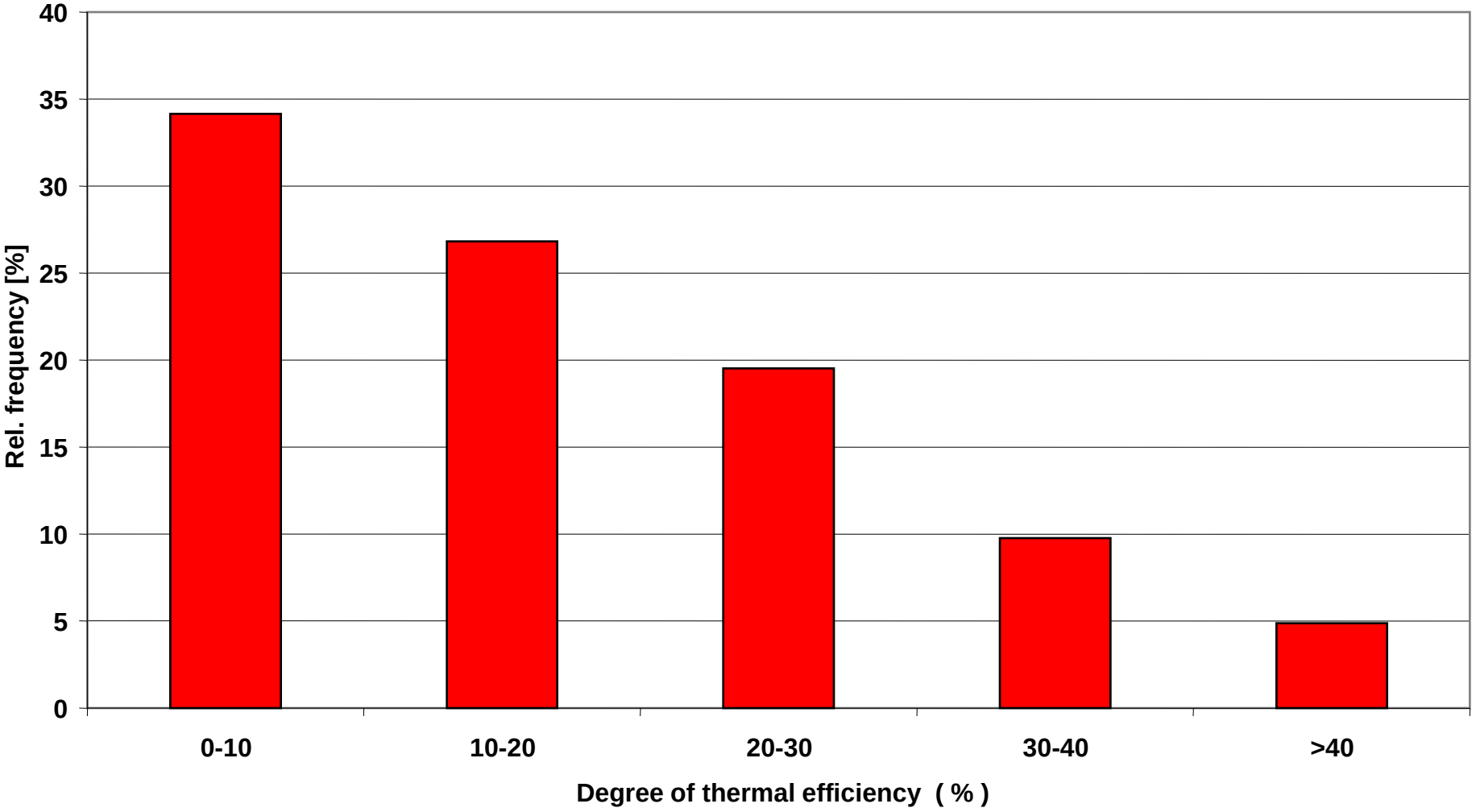
**<u>2007 – 2008</u>: Monitoring of 78 biogas plants in province Lower Austria**


Used substrates (% VS)
used substrates [% VS]
100%
80%
60%
40%
20%
0%
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
biogas-plant-number
energy crops %
manure %
co-substrates %
bio-waste %

# Utilisation of fuel energy



# Degree of thermal efficiency



# Operational parameters of 41 full scale energy crop digestion plants in Austria

| Parameter | Unit | Median | min. | max. |
|---|---|---|---|---|
| Amount of processed substrate | $t_{Substrate}/d$ | 13.2 | 0.8 | 58.9 |
| Hydraulic retention time (days) | $m^3_{RV}/(t_{Substrate}/d)$ | 131 | 44 | 483 |
| Organic load (dry substance) | $kg_{VS}/(m^3_{RV}\cdot d)$ | 3.59 | 1.04 | 7.97 |
| COD load | $kg_{COD}/(m^3_{RV}\cdot d)$ | 5.64 | 1.62 | 11.95 |
| Amount of VS dosed | $t_{VS}/d$ | 2.34 | 0.33 | 13.78 |
| Biogas generation per day | $Nm^3_{biogas}/d$ | 1,461 | 233 | 10.115 |
| Biogas productivity | $Nm^3_{biogas}/(m^3_{RV}\cdot d)$ | 0.96 | 0.22 | 2.17 |
| Carbon degradation | % | 82.8 | 61.5 | 96.8 |
| Average biogas yield | $Nm^3_{biogas}/ kg_{VS}$ | 0.662 | 0.511 | 0.878 |
| Methane content in biogas | % | 54.8 | 49.7 | 67.0 |
| Electrical efficiency | % | 31.3 | 20.7 | 39.2 |
| Use of heat (related to total input energy $H_{u, biogas}$) | % | 16.5 | 0.0 | 42.6 |
| Annual use efficiency (related to total input energy $H_{u, biogas}$) | % | 47.3 | 30.5 | 72.3 |

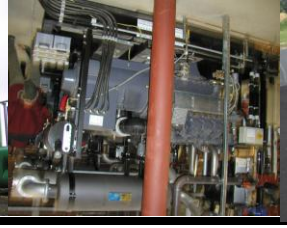
RV: Reactor volume; $H_{u, biogas}$: Net calorific value of biogas; VS: Organic matter

# The energy balance of Energy Crop digestion (O : I)

$$O : I = \frac{\text{Overall Energy Output}}{\text{Overall Energy Input}}$$







Cultivation
Fertilizer

Pestizides
Transport

Ensilage
Silo cover

Dosage

Process energy-demand

On-site power
Motor oil demand
Methane losses

Digestate use

| Plant 1 | Plant 2 | Plant 3 | Plant 4 | Plant 5 |
|---|---|---|---|---|
| Maize & other plants,<br>agricult. by- pro-ducts, manure<br>No use of synthetic fertilizer<br>2-step plant<br>500 $kW_{el}$ | Only renewable biomass (Maize, grass),<br>no manure<br>Synthetic fertilizer appl. (base fertilising)<br>2-step plant<br>500 $kW_{el}$ | Oil seed residues, Fat trap contents, waste from food & feedstuff industry; waste food, beet sugar by-products; renewable biomass on occasion<br>2-step plant<br>1.672 $kW_{el}$ | Mainly manure (62 % cattle- and pig manure)<br>Food leftovers and potato slops;<br>2-step plant<br>200 $kW_{el}$ (ignition oil applied in CHP) | Conventional manure treatment (90 % pig manure and chicken litter), small amounts of fat trap contents<br>Gas displacement system with hydraulic mixing<br>18 $kW_{el}$ (η CHP only 22 %) |

| | Plant 1 | | Plant 2 | | Plant 3 | | Plant 4 | | Plant 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Maize & agric. By-products, manure No synth. fertilzer, 2-step plant, 500 $kW_{el}$ | | Maize, Clover grass, no manure, Synthetic fertilizer, 2-step plant, 500 $kW_{el}$ | | Biowaste, Renewable raw materials on occasion 2-step plant, 1.672 $kW_{el}$ | | manure (60%), Food leftovers, Destill. slops 2-step plant 200 $kW_{el}$ (Ignition oil in CHP) | | Manure (90%), Fat trap contents; 18 $kW_{el}$ (η CHP only 22 %) | |
| | **Input** | **CED** | **Input** | **CED** | **Input** | **CED** | **Input** | **CED** | **Input** | **CED** |
| ***O:I** Power/Heat* | *17.8* | *8.1* | *14.7* | *6.7* | *20.9* | *9.9* | *2.4* | *1.1* | *30.9* | *14.7* |
| ***O:I** Power* | *11.7* | *5.4* | *10.5* | *4.8* | *20.9* | *9.9* | *2.1* | *1* | *14* | *6.7* |
| **O:I** Power/Heat | 18.7 | 8.6 | 14.7 | 6.7 | 8.7 | 4.1 | 2.5 | 1.2 | 34.4 | 16.5 |
| **O:I** Power | 12.4 | 5.7 | 10.5 | 4.8 | 8.7 | 4.1 | 2.2 | 1.1 | 15.7 | 7.5 |

**O:I-ratio severely influenced by the degree of heat use**

**O:I-ratio severely influenced through transport energy demand**

**O:I-ratio severely influenced through use of ignition oil**

**Favour-able O:I-ratio in manure digestion**

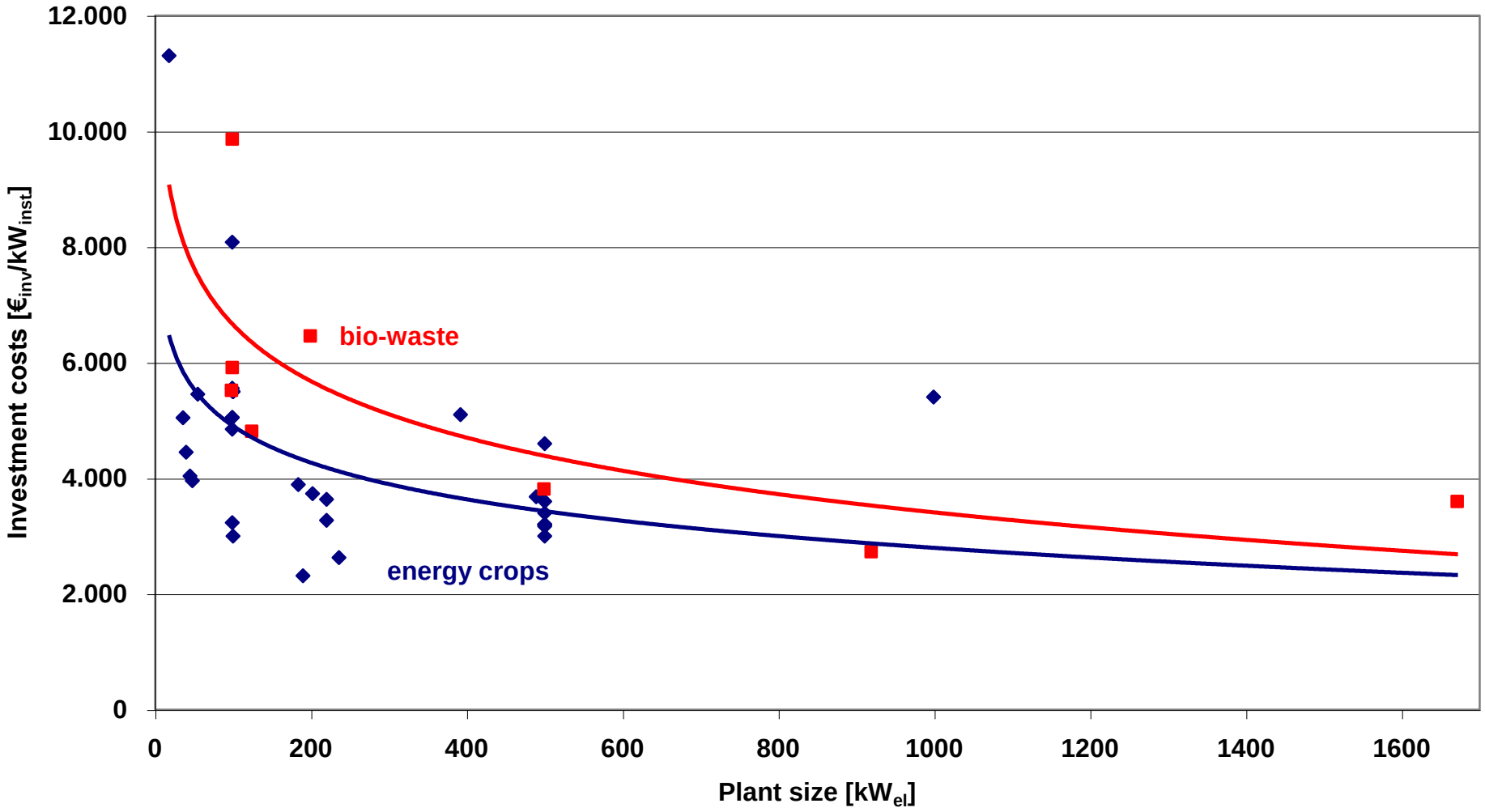
# Comparative < Output : Input > - Efficiencies of Bioenergies

| | |
|---|---|
| Plant oil* | 3.2 |
| Biodiesel* | 3.9 |
| Ethanol* | 1.25-2 |
| BtL* | 7.9 |
| Hydrogen* | 4 |
| Biogas* | 2.7 |
| **Own measurements (including CED**)** | |
| **Plant 1 (Renewables & agric. by-products)** | **8.6** |
| **Plant 2 (Renewables )** | **6.7** |
| **Plant 3 (bio-waste, partly. renewables )** | **4.1** |
| **Plant 4 (manure, Co-substr., ignition oil CHP)** | **1.2** |
| **Plant 5 (manure)** | **16.5** |

*) Data source: FNR (2006); **) Cumulative Energy Demand

# The economics of Energy Crop digestion

# Investvestment costs



# Profitableness?

## Multiple influential factors!

**Investment costs:** 2,000-4,000 €/kWh

**Raw material costs:** 60-190 €/t maize

**Plant performance (efficiency):** 30-72%

**Subsidies (building, capital, energy)**

**Energy price (gas, power, heat, fuel)**

# Energy crop digestion plant 500 $kW_{el.}$ – Economics estimation

3,979 t maize (corn, 30 % $H_2O$) / year
1,800,000 $m^3$ biogas (50 % $CH_4$) / year
3,718 MWh/a power
1,600 MWh/a heat
5,318 MWh/a total energy used

| | Case 1 | Case 2 |
|---|---|---|
| Investment costs (€) | 2,000,000 | 2,000,000 |
| Amortisation (13 years) | 153,850 | 153,850 |
| Raw material costs | 278,530 | 736,115 |
| Other costs | 43,238 | 43,238 |
| Total costs (€ / year) | 475,618 | 933,203 |
| Revenue (€ / year) | 595,616 | 595,616 |
| Profit / Loss (€ / year) | **+119,998** | **-337,587** |

# CONCLUSIONS

- **Most plants depend on external substrates (crops)**
- **Due to high raw material costs, many biogas plants suffered on economic losses in 2008**
- **Most plants have just a poor or even missing concept for heat use and hence low energy efficiency**
- **Only a small minority of the plants consider more efficient biogas use (upgrading to natural gas quality, gas grid injection, use as fuel)**
- **20 % of all plants use open substrate storage**
- **40 % of the plants use uncovered digestate storage tanks / lagoons**

# Thank you for your attention!

**Acknowledgement**

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