WASTEWATER SLUDGE AS A RESOURCE

- Sludge disposal strategies
- Treatment strategies for stabilization Hygienisation
- Productification of sludge

Hallvard Ødegaard

FINAL SLUDGE DISPOSAL OPTIONS

DEPOSITION/CONTAINMENT
- On land – landfills – phasing out
- In the ocean – phased out
- Incineration ash deposition

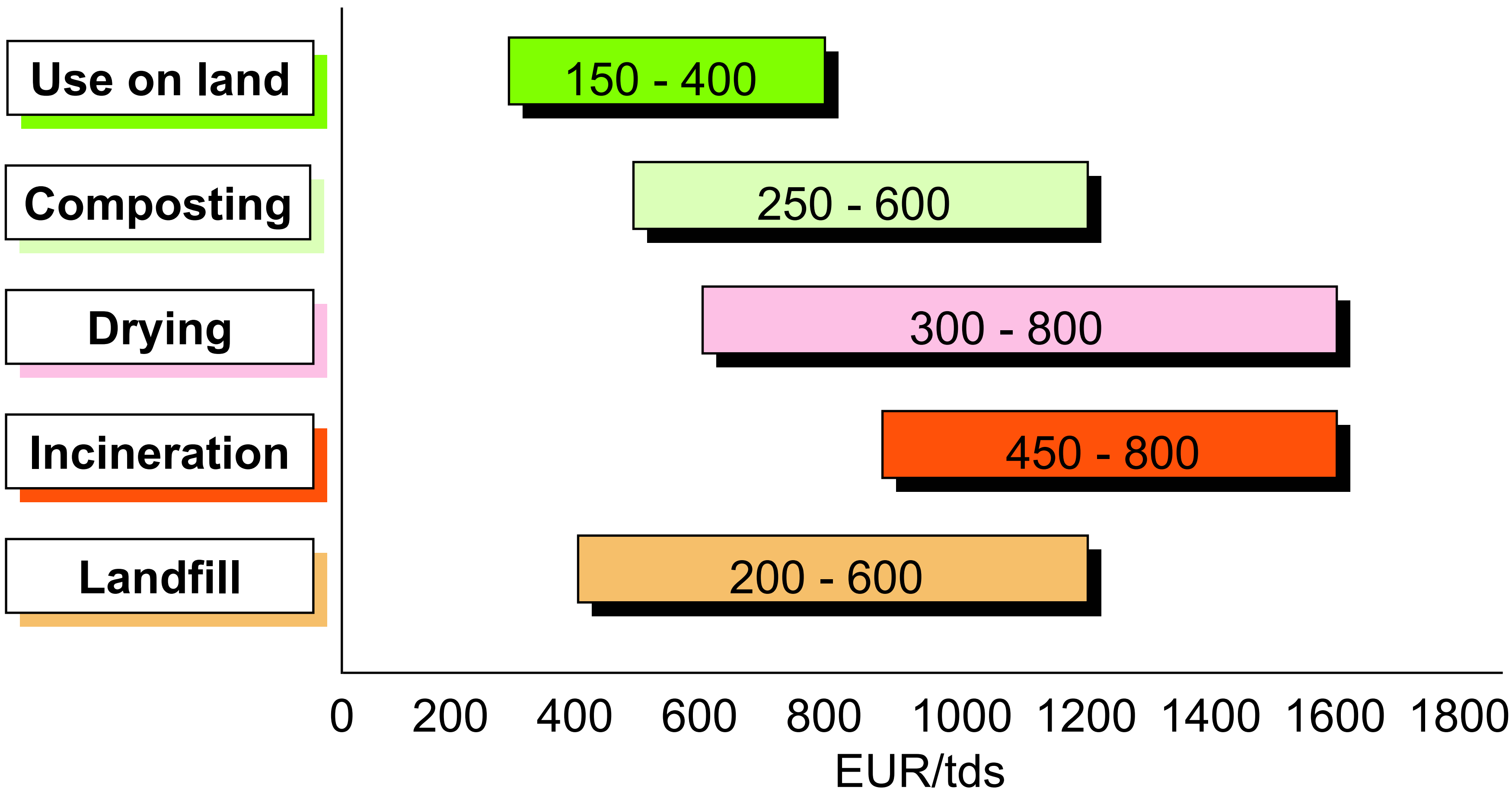
RECYCLING (”PRODUCTIFICATION”)
- Production of ”bio-soils”
- Recovery of phosphate
- Recovery of energy

USE ON LAND
- Direct use on farmland as fertilizer/soil conditioner
- Use of ”bio-solis” (constructed soils) on green areas

Quantity and disposal of communal sludge in EU (in 1000 tons of dry solids)

	1984		1992		2000		2005	
Utilisation	2.057	37	2.504	39	3.617	40	4.576	45
Incineration	518	9	715	11	2.088	24	3.872	38
Landfill	3.988	54	3.257	50	3.200	36	1.615	17
Total	5.563	100	6.476	100	8.906	100	10.063	100

SLUDGE TREATMENT AND DISPOSAL COSTS (EUR/ton DS)
(J. Hall, 2000 – WrC, UK)



THE "USE ON LAND" STRATEGIES

DIRECT USE ON FARMLAND

The most commonly used and probably the most sustainable sludge resource recycling option !

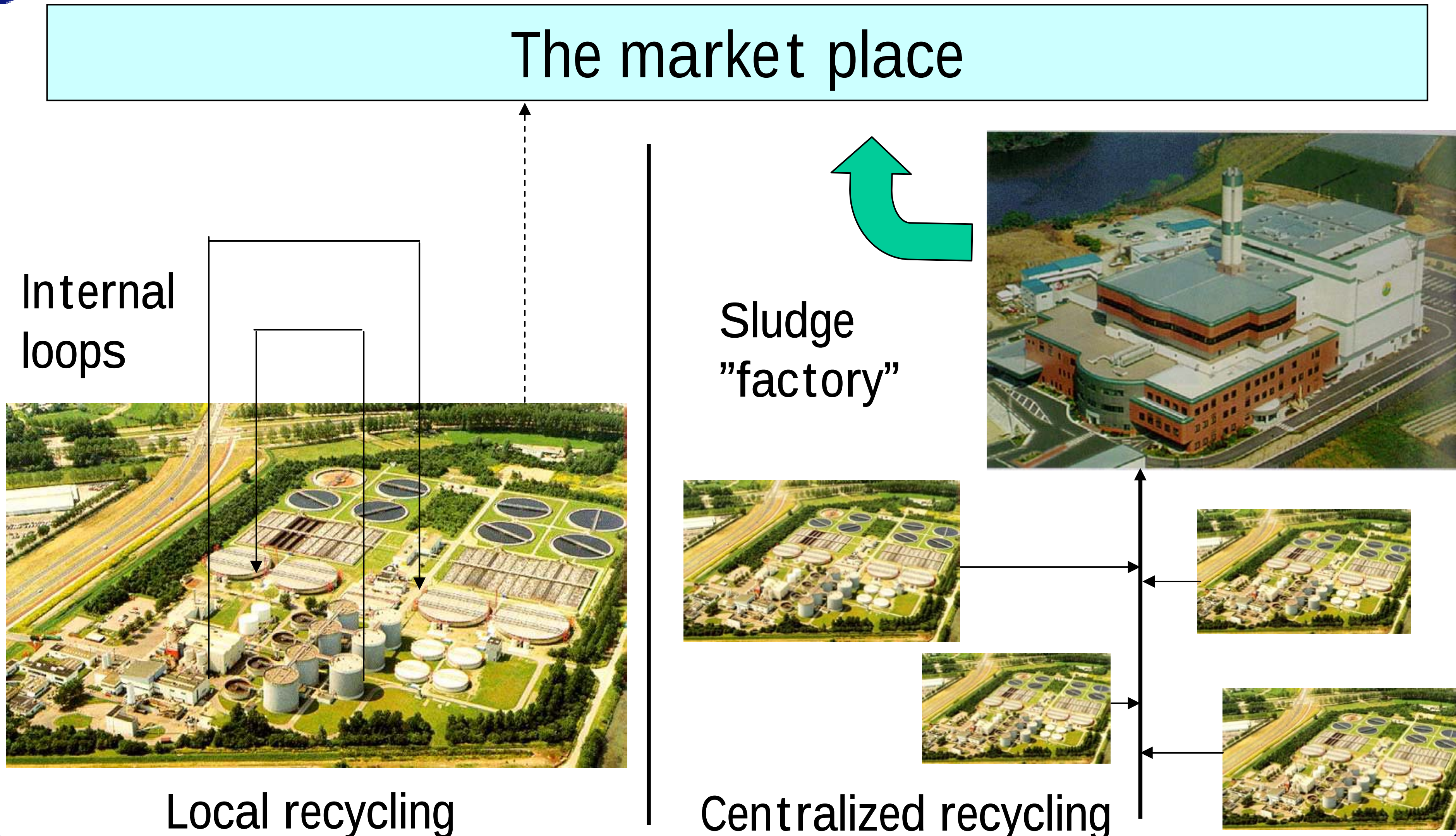
But : Under considerable threat !

USE OF "BIO-SOILS" ON "GREENS"

Bio-soils: Mixture of treated sludge, filling materials (sand, clay, bark etc) and nutrients (N,P,K)

Primarily used on green areas (parks, sporting fields, gardens, green houses)

RECYCLE/PRODUCTIFICATION STRATEGIES



TREATMENT OF SLUDGE IN THE ”USE ON LAND” STRATEGY

EU New sludge diretive (Working document, Brussels 27. April, 2000)
”Sludge should be used on land whenever possible
and only according to relevant Community or national legislation”

Conventonal treatment	Advanced treatment
• Aerobic stabilization (batch) • Mesoph. anaerob. stab. (35°C, 15 days) • Thermoph. aerob. stab. (55°C, 20 days) • Thermoph. anaer. stab. (53°C, 20 days) • Lime cond. (pH>12 over at least 12 hrs)	• Lime cond. (pH>12 over at least 3 mnts) • Lime cond. (pH>12 and > 55 °C ≥ 2 hrs) • Therm. treatm. (≥ 70°C, 30 min) + mesoph. anaer. stab. (35°C, 12 days) • Therm. anaer. stab. (53°C, 20 hrs batch) • Therm. aerob. stab. (55°C, 20 hrs batch) • Thermal drying (> 80°C, DS> 90 %)

Dewatering av sludges included

Specified reduction of pathogens

NORWEGIAN REGULATIONS

- Regulation for sludge treatment and disposal since 1995 (practiced since 1990)
- Pronounced authority goal in 1995 :
  75 % of sludge produced used on land within 2000
  Situation 1999 : 79 % (69 % on farmland, 10 % on green-fields)
- Regulations based on:
  - Maximum contents of heavy metals (lower limits of EU-directive)
  - Crop restrictions (not on vegetables, potatoes, fruits) until 3 yrs
  - Not allowed to be spread on grazing land
  - Liquid sludge not allowed - Spread on frozen land not allowed
  - Maximum application rate (20 tons DS/hectar per 10 years)
  - Treatment requirement: Stabilization, disinfection, dewatering

New coordinated regulations on use of organic fertilizers (including sludge and ”bio-soils” made from sludge) under approval procedure

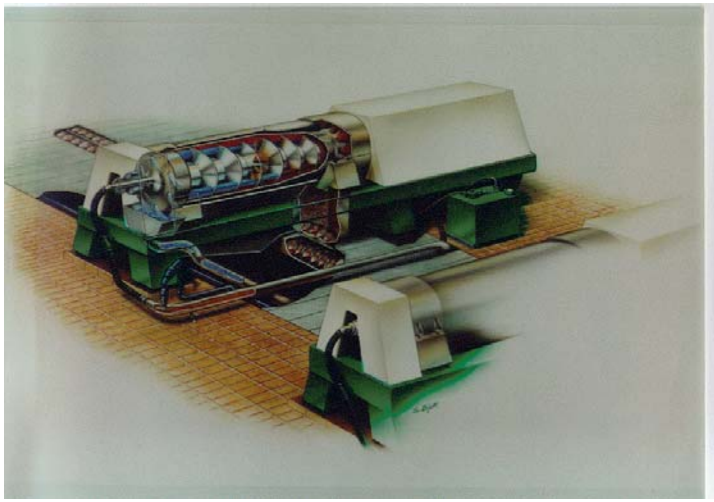
NORWEGIAN AND EU REGULATIONS ON METAL CONTENT OF SLUDGE TO BE USED ON LAND

Element	Norwegian regulations		EU regulations	
	Farmland	Green fields	Dir 86/278/EEC	Proposed
Cd	2	5	20-40	10
Pb	80	200	750-1200	750
Hg	3	5	16-25	10
Ni	50	80	300-400	300
Zn	800	1500	2500-4000	2500
Cu	650	1000	1000-1750	1000
Cr	100	150	-	1000

TREATMENT REQUIREMENTS FOR DIRECT USE ON LAND

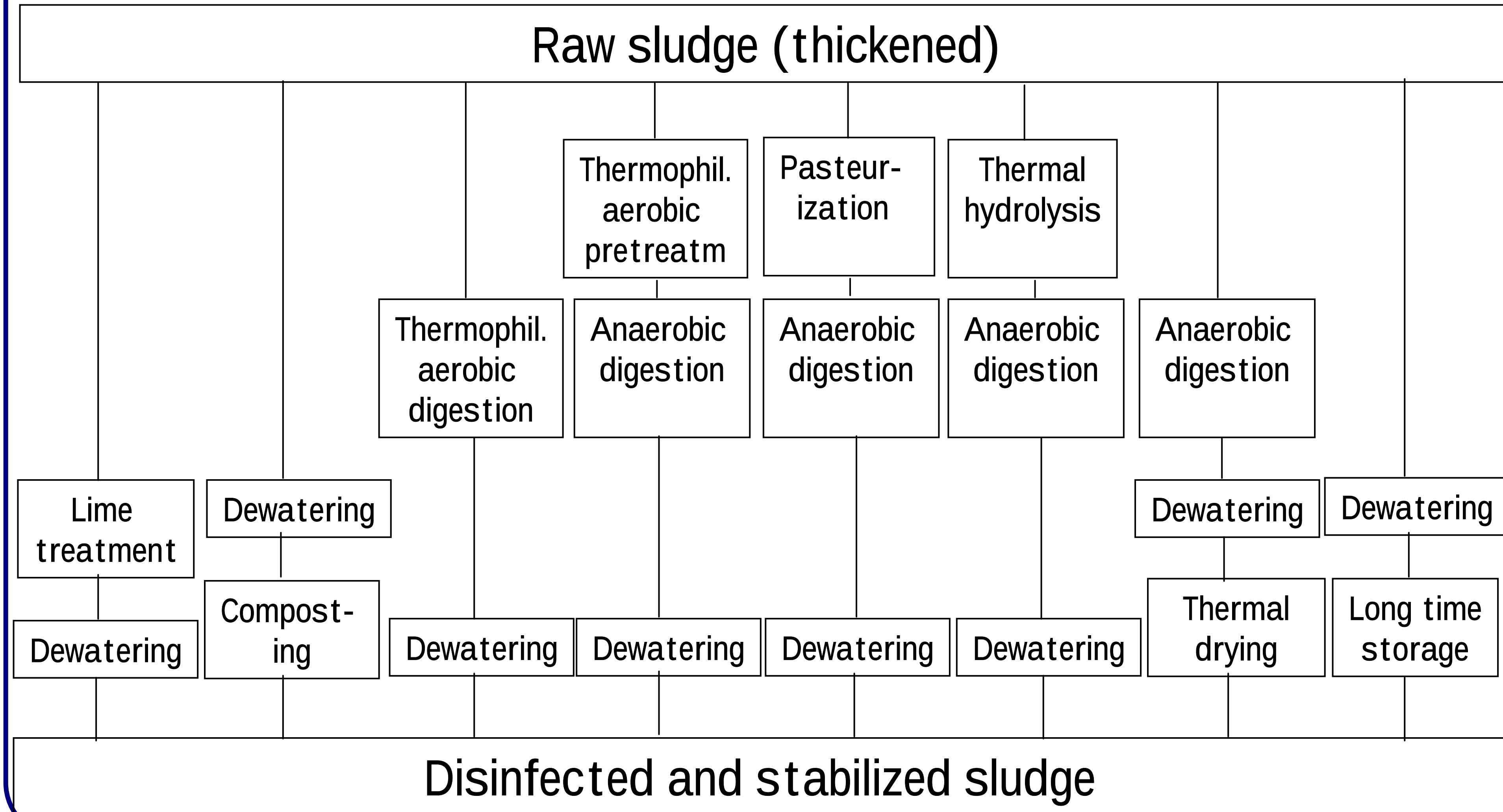
HYGIENIZATION –
to prevent infection of people and animals

STABILISATION –
to prevent odour



DEWATERING –
to ease the spreading of sludge on farmland

APPROVED METHODS FOR DISINFECTION & STABILIZATION IN NORWAY



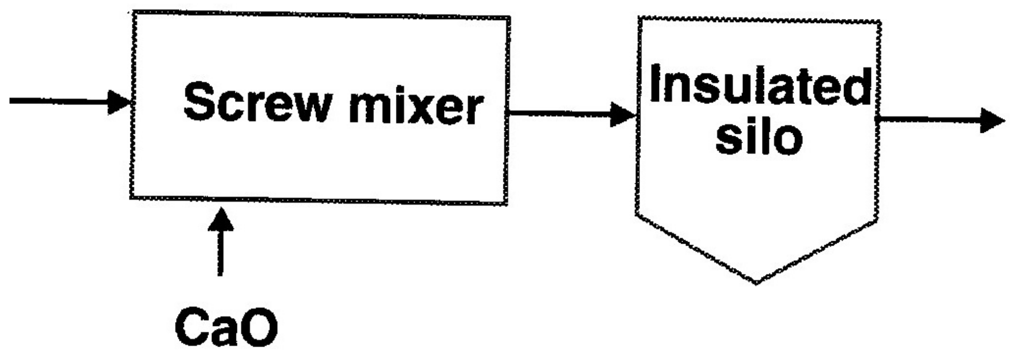
LIME TREATMENT
Addition of quicklime to dewatered sludge

Design and operational criteria:

- Min. 2 hours at ≥ 55 °C
- Min. 2 hours at pH ≥ 12

Experiences :

- Mainly at small and medium-sized plants
- High dose neccessary
  (typically: 500 kg CaO/ton TS)
- Low investment, high OM cost
- Granular consistency - easy to spread



COMPOSTING

Design and operational criteria:

Windrow or aerated static pile:

- Min. 3 weeks at ≥ 55 ºC
- Min. 1 turn of windrow in 3 w.

Reactor (in vessel):

- Min. 10 days at ≥ 55 ºC
- Min 2 days at ≥ 65 ºC
- Min 2 weeks maturing

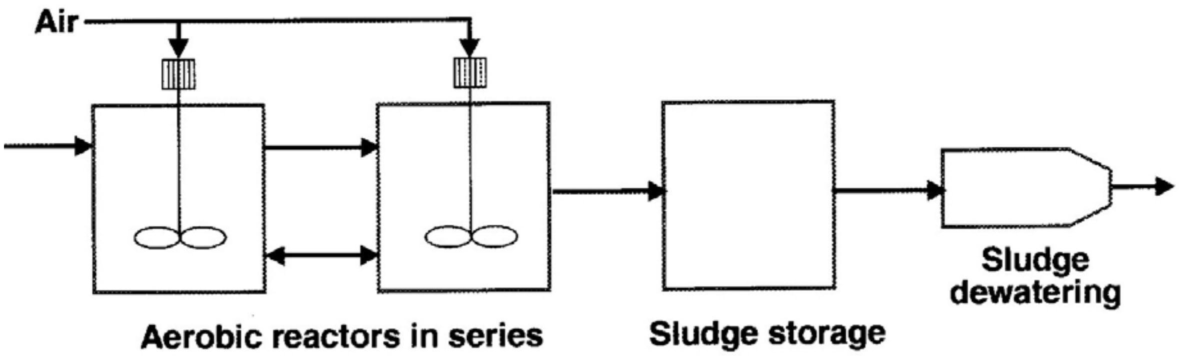
Primarily used at:

- Small and medium-sized plants
- Chem. and biol./chem. plants

Experiences :

- Variabel hygienic quality in windrow plants
- Good in dry and warm weather
- Bulking agent very important
- Better experien. in reactor plants

THERMOPHILIC AEROBIC DIGESTION
Wet composting



Design and operational criteria:

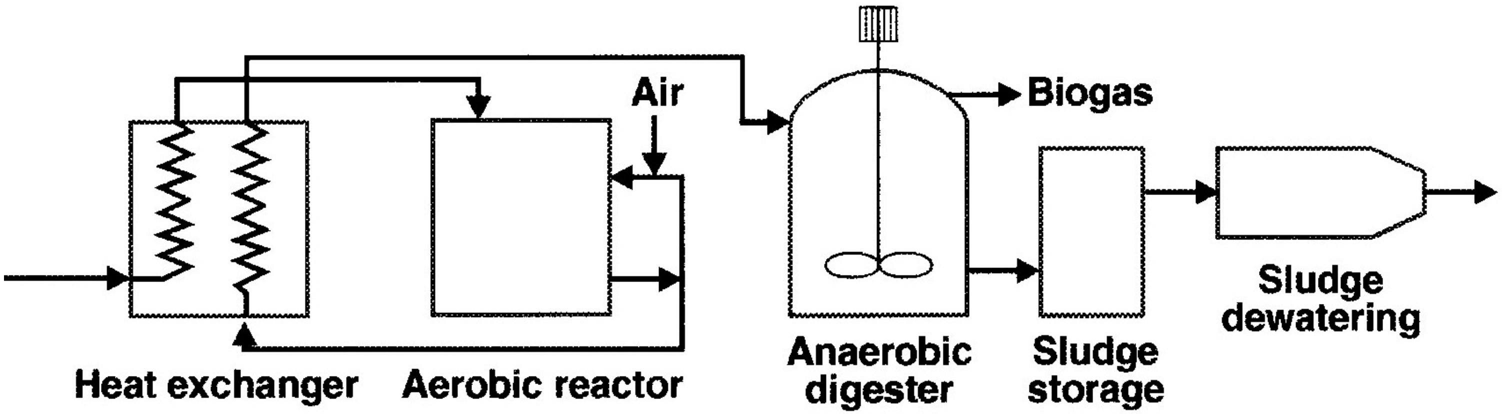
- Min. 2 reactors in series
- Min. 23 hours at 50 ºC or
  min. 10 hours at 55 ºC or
  min. 4 hours at 60 ºC
- Min. 7 days aver. res. time

Experiences :

- Min. conc. in feed sludge: 2,5 %
- Aver. VSS-red.: 43 %
- Comply with disinfect. standard

.

THERMOPHILIC AEROBIC PRETREATMENT + ANAEROBIC DIGESTION



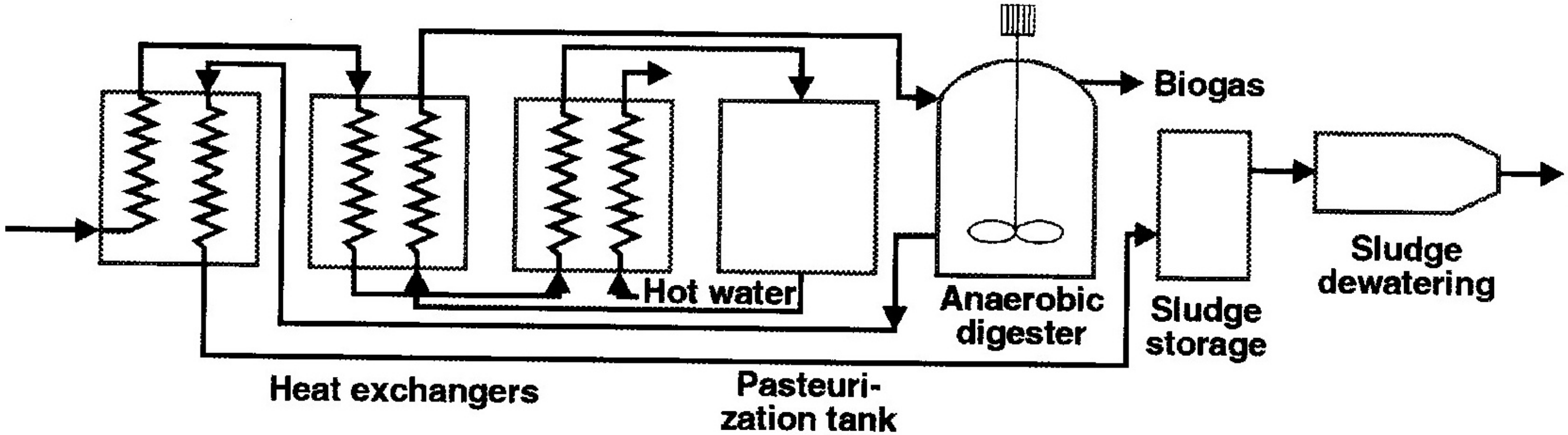
Design and operational criteria:

- Min 4 hrs at min 60 °C in aerobic pretreatment reactor
- Min 12 days at min 35 °C in anaerobic digestion reactor.

Experiences :

- Mainly at medium and large plants
- Complying well with standards
- Gas prod.: ~ 1.0 $m^3/kg\ VS_{red}$
- Polymer consumpt.: ~ 3 g/kg DS
- VS-reduction : 35-45 %

PRE-PASTEURIZATION + ANAEROBIC DIGESTION



Design and operational criteria:

- Min 30 min at min 70 ºC in pasteurization reactor
- Min 15 days at min 35 ºC in anaerobioc digestion reactor

Experiences:

- Mainly at medium-sized and large plants
- Complying well with standards
- Gas production: ~ 1.0 $m^3/kg\ VS_{red}$
- Polymer consumpt.: ~ 3,0 g/kg DS
- VS-reduction : 35-45 %

THERMAL HYDROLYSIS + ANAEROBIC DIGESTION

Design and operational criteria:

The CAMBI process:

- Typically 30 min at 160 °C in thermal hydrolysis
- Typically 15 days at min 35 °C in anaerobic reactor.

Basic idea:

To increase:

- VS-reduction
- Biogas production
- Dewatered sludge concentration

by thermal hydrolysis

Disinfection assured at oper. cond.

The CAMBI thermal hydrolysis process

Steam used as heat source to raise temperature in three steps:

- to 80 °C by heat exchangers
- to 120 °C by recycling flash steam
- to 160 °C by injection of steam in reactor

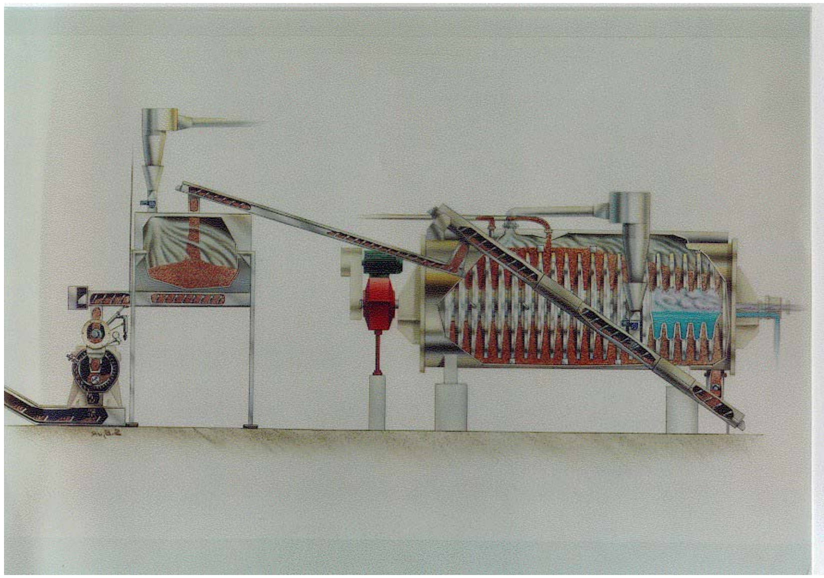
ANAEROBIC DIGESTION + THERMAL DRYING

Design and operational criteria:

- Minimum 15 days at min 35 °C in anaerobic digester (or thermophilic).
- Typically 30 min. at 80-90 °C in dryer

Experiences :

- Becoming very popular
- Complying well with standards
- Several operation problems with dryers (lack of competence?)
- Dried sludge (90 % DS) dust problem – pelletizers installed



Primarily used at:

- Medium-sized and large plants
- Chem. and biol/chem. plants

Is drying sustainable ?

COST COMPARISONS

Gardermoen WWTP – 3.730 ton DS/year

(1995 prices, 1 EUR = 8,1 NOK, ** 7 % interest rate, 20 years depreciation time)

Methods for stabilization and disinfection	Tot. cap. cost (mill. NOK)	O & M cost (mill NOK/year)
Therm. aerobic pre-treatm. + anaer. digest.	36.0	3.15
Pre-pasteurization + anaerobic digestion	36.0	3.15
Anaerobic digestion + thermal drying	46.5	3.25
Reactor composting	48.2	3.95
Quicklime treatment of dewatered sludge	25.3	4.95

Methods for stabilization and disinfection	Annual cost **	
	mill. NOK/year	NOK/ton DS
Therm. aerobic pre-treatm. + anaer. digest.	6.55	1,750
Pre-pasteurization + anaerobic digestion	6.55	1,750
Anaerobic digestion + thermal drying	7.64	2,050
Reactor composting	8.50	2,280
Quicklime treatment of dewatered sludge	7.35	1,970

RECYCLING OF SPECIFIC PRODUCTS FROM SLUDGE THE ”PRODUCTIFICATION” STRATEGY

Necessary driving forces:

- The urge to “get rid of” or minimize the sludge
- The demand versus the general availability of this resource on the globe
- The cost of the recycled product versus market price

Possible strategies for utilizing the diversified sludge as raw material:

- To get rid of ”the bad things” and utilize mixture, i.e bio-soils
- To extract ”the good things” and leave the residue as not marketable

The ”good things” to utilize:

- Carbon (for energy)
- Nutrients (for fertilizer)
- Fe/Al (for coagulants)

The ”bad things” to get rid of:

- Pathogens
- Heavy metals
- Organic micro-pollutants

PRODUCTS FROM THE "PRODUCTIFICATION" STRATEGY

Soil products ("Bio-soils")

- Mixture of :
  - Treated sludge
  - Filling materials (sand, clay, bark etc)
  - Nutrient additives (N,P,K)
- Asked for in the market place
  - Public use (parks, sporting fields, road embankments)
  - Private use (gardens)
- Product must be approved by health and agriculture author.

Specific recycle products

- Energy in the form of
  - Biogas from anaerobic digestion
  - Electricity from biogas
  - Biofuel from dewatered sludge
  - Heat from biogas and incineration
  - Oil from pyrolysis
- Fertilizers in the form of
  - Organic matter
  - Phosphorous
  - Nitrogen (from the sludge water)
- Carbon source for N-removal
- Coagulants (aluminium, iron)
- Building materials additives (ash)

THE MARKET POTENTIAL OF THE PRODUCTS

Resource	Genarally marketable	Locally marketable	In plant recyclable	Market potential
Bio-soils	Yes	Yes	No	Good
Energy				
Electricity	Yes	Yes	Yes	Good
Heat	No	Yes	Yes	Fair
Biofuel	May be	Yes	Yes/No	Bad
Oil	Yes	No	No	Bad
Nutrients				
Phosphate	Yes	Yes	No	Fair
Nitrogen	No	No	No	Bad
Coagulants	No	No	Yes	Bad
Other metals	No	No	No	Bad
Build.matr.add	No	May be	No	Bad

Only bio-soils, electricity, phosphate and heat seem to have a potential

EXAMPLES FROM USE OF ”BIO-SOILS” IN TRONDHEIM

EXAMPLES FROM USE OF ”BIO-SOILS” IN TRONDHEIM

SUITABILITY FOR DIFFERENT PURPOSES OF BIO-SOILS TREATED BY VARIOUS METHODS

Example of a constructed biosoils:
20 % treated sludge, 30 % bog, 50 % mineral soil + nutrient additives

Suitable for	Lime treated	Windrow compost	Reactor compost	Therm. aerob	Anaerob disinfect	Anaerob & dried	Long storage	Dried raw
Farmland	+++	++	++	++	++	++	++	+++
Topsoil	-	+	++	+	+	+++	-	-
Roadsides	+	++	+++	+	+	+++	-	+
Skiarenas	+	++	+++	+	+	+++	-	+
Landscaping	++	++	+++	+	+	+++	+	++
Energy forest	+	+	++	+	+	++	+	+++
Ready lawn	-	+	++	+	+	++	-	-
Plant schools	-	-	-	-	-	++	-	-

ENERGY RECOVERY FROM SLUDGE

Biogas produced by anaerobic digestion of sludge

Heat produced by sludge incineration

Hot water

Electricity

Hot gas/water

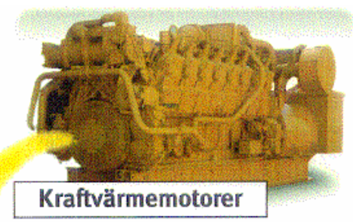
Heat - low quality energy - requires receptor - plant itself or heat distributor

High quality energy - Exergy - that part of energy that can be converted to any other form

ENERGY FROM BIOGAS

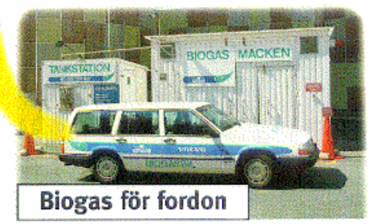
Total	2,1 kWh/kgDS
Electricity	0,7 kWh/kgDS
(potential in EU :	6 TWh/year)
Heat	1,4 kWh/kgDS
Recoverable heat	1,0 kWh/kgDS
Digester heating	0,7 kWh/kgDS
Waste heat	0,4 kWh/kgDS

Gas storage

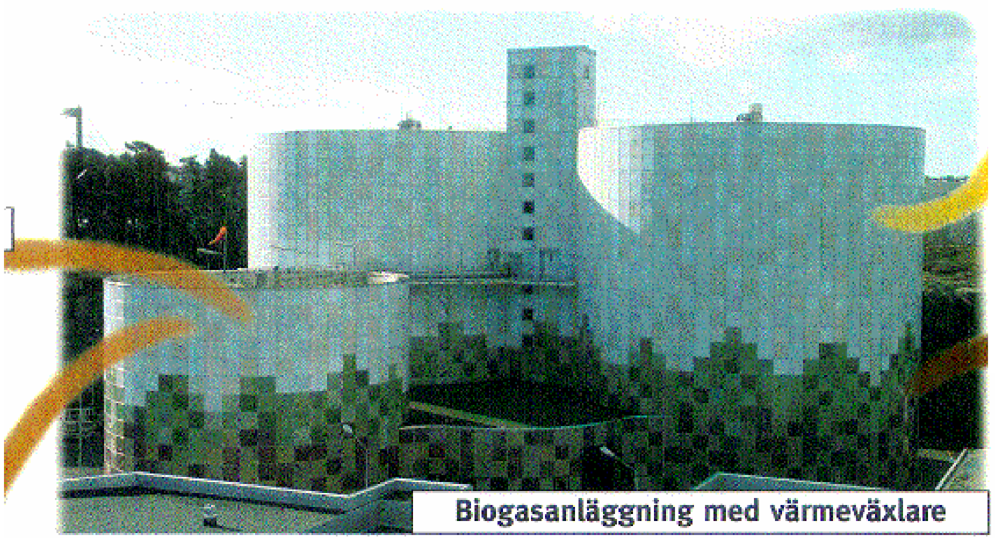


Heat power engine for el-production

Boiler for heat product.



Biogas for car-fuel



Biogas plant with heat exchangers

NTNU - Norwegian University of Science and Technology
Dep. Hydraulic and Environmental Engineering

Prof. Hallvard Ødegaard

Heat from incineration

Heat value of raw sludge : 14 MJ/kgDS (3,85 kWh/kgDS)
----”---- digested sludge : 12 MJ/kgDS (3,30 kWh/kgDS)
The biogas potential should be taken out before incineration

The energy needed for evaporation of the water is balanced by the energy produced by incineration at a sludge DS of about 25 %.
Higher DS gives a net heat amount

Typical process solutions :

Dewat.	Drying	Inciner.	
Hydrol.	Dewat.	Inciner.	
Hydrol.	Digest.	Dewat.	Inciner.
Dewat.	Drying.	Bio-Pellets	

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Dep. Hydraulic and Environmental Engineering

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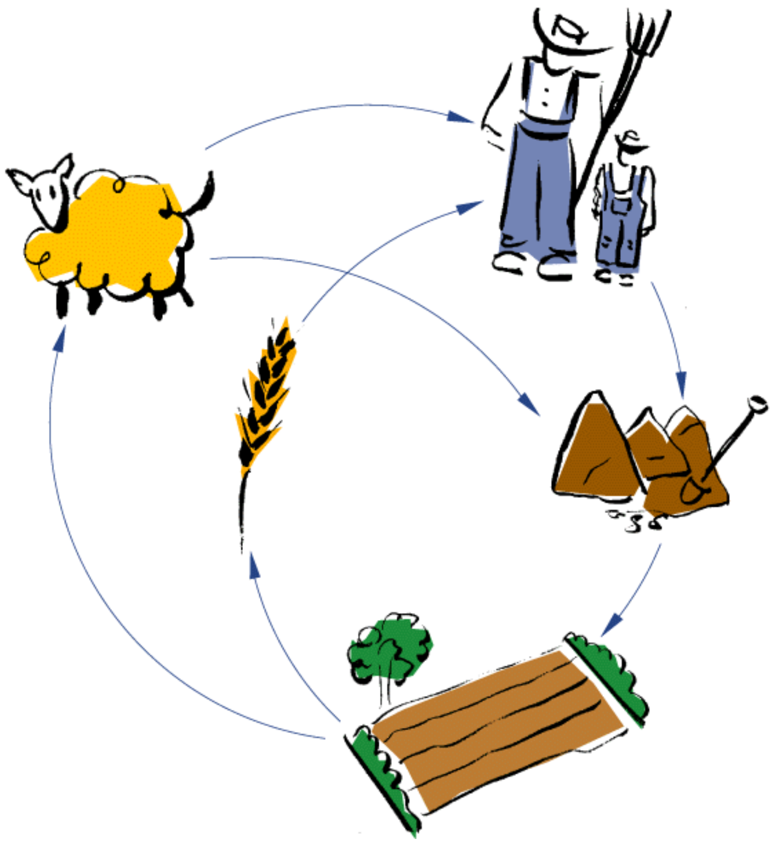
PHOSPHATE RECOVERY

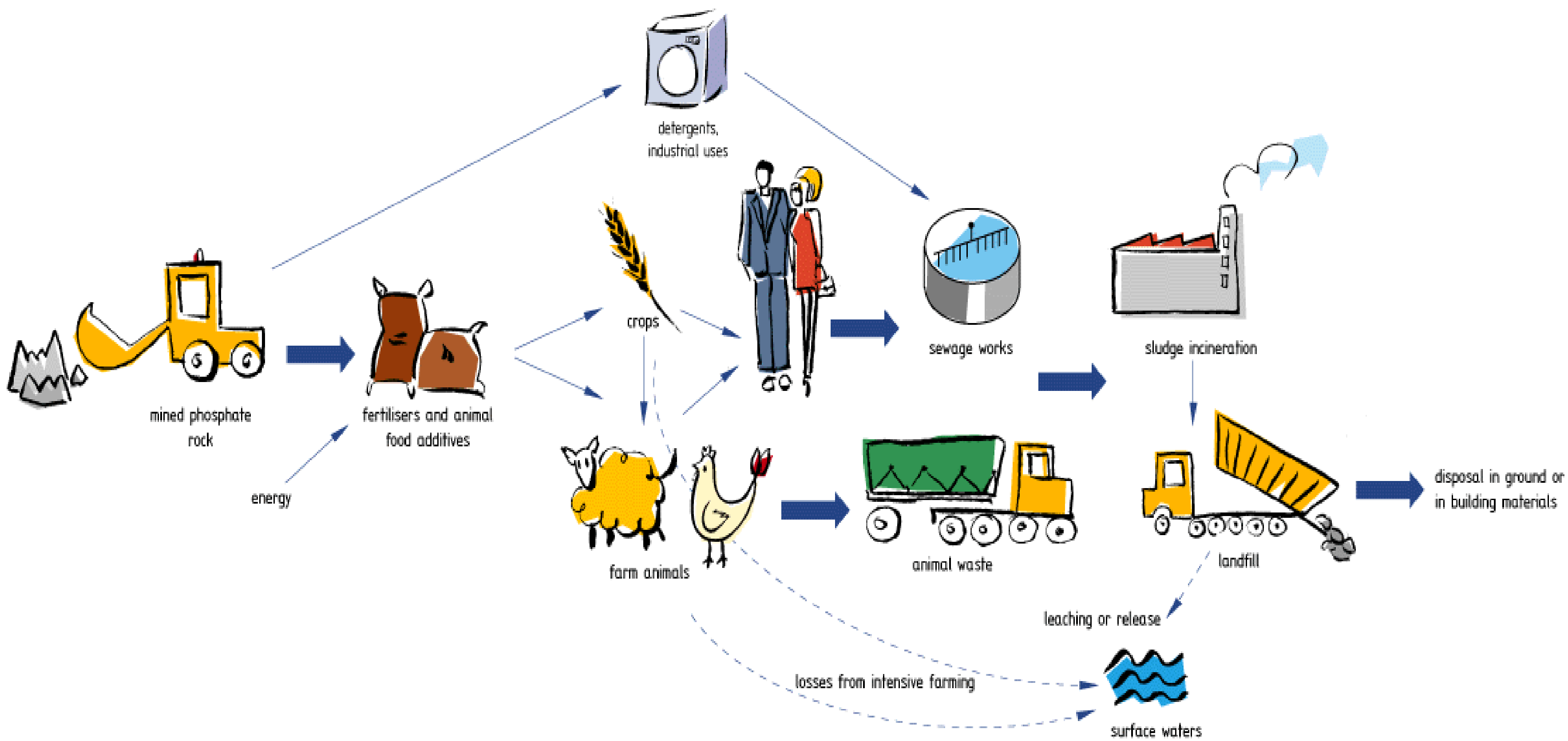


Traditional P-cycle

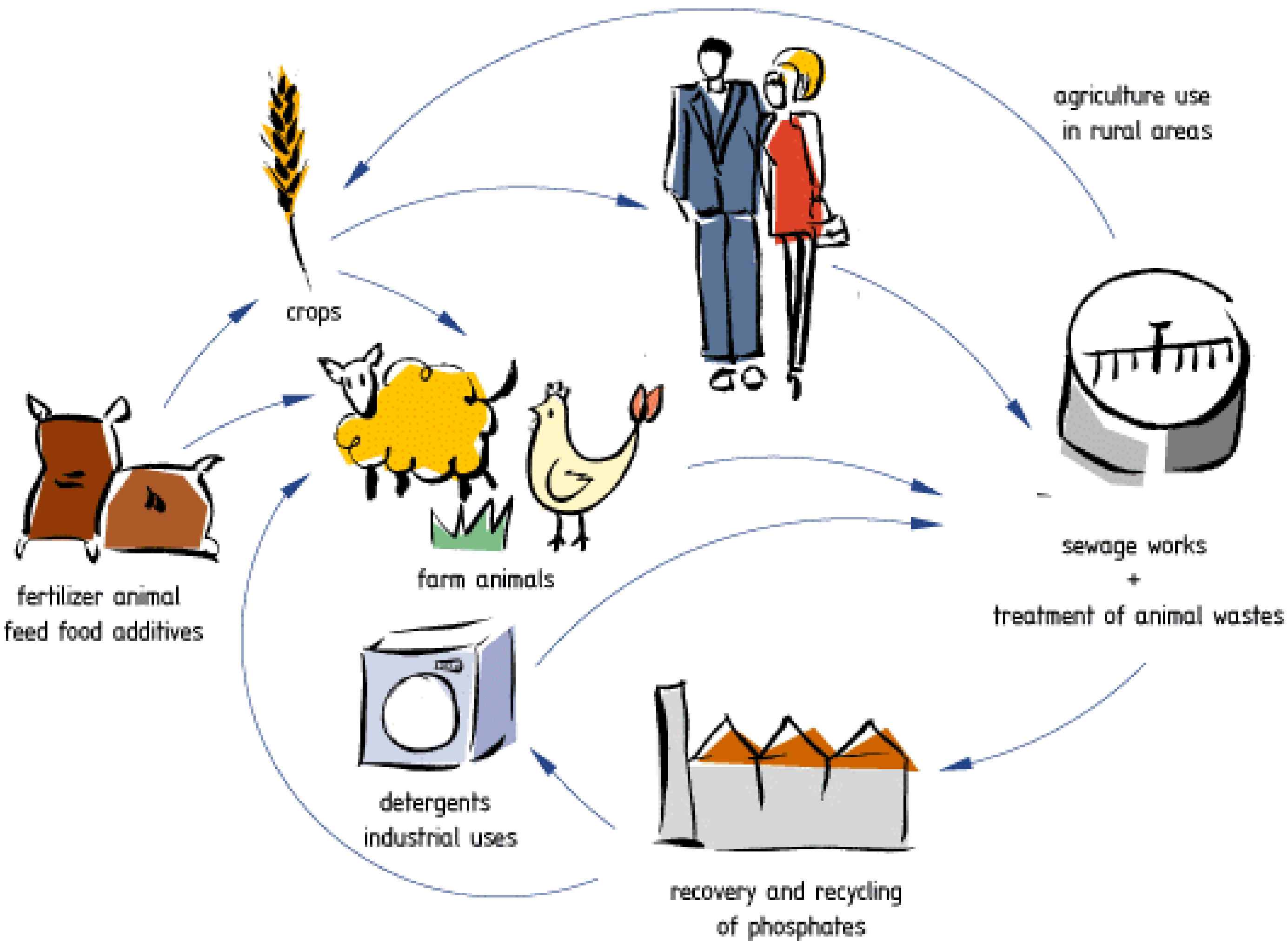
Stimulating factors for recovery:
EC Wastewater Directive
- Limits to sludge spreading
- High sludge treatment costs
- P-recovery policy of industry
- P-recovery policy of government
- Struvite deposit problems
- P-resources demand

Drivers for the water industry
- Potential for cost savings
- Potential for cost recovery
- Potential for improved P-removal

Modern throughput P-system



Future P-cycle



FOSFORGJENVINNINGSPROSESSER

Med dagens forbruk og pris vil vi ha råfosfat i 50 år til – i 100 år til om vi dobler prisen

Teknologier:

- Jernfosfatutfelling
  - KREPRO
- Calciumfosfatutfelling
  - Crystallactor
- MAP-utfelling
  - Phosnix
- Gjennvinning fra aske

Crystallactor

Phosnix

PHOSPHATE RECOVERY TECHNIQUES

Beneficial with a P-concentrated stream:

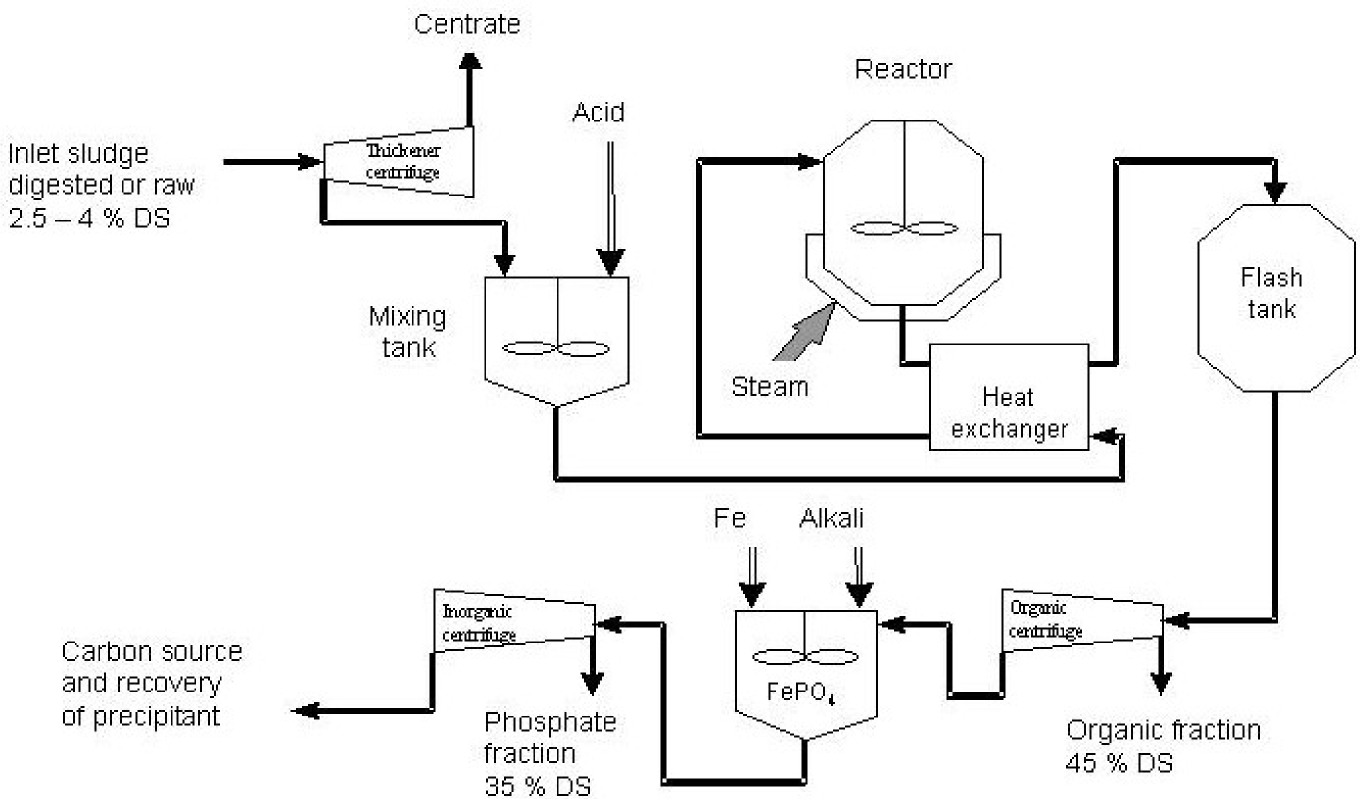
- Bio-P sludge (or in sludge water from P-released bio-P sludge
- Chemically precipitated sludge (or P-released from such)

Feasibility depends strongly on circumstances in each country.
Determining factors are:

- P-concentration in influent
- Sludge handling costs
- Costs of the P-recovery technique
- Market value of P-recovery product

Calculated cost for P-recovery when used on land : 3 US$/kgP
Calculated cost for P-recovery from ash : 6-8 US$/kgP

EXAMPLE OF A SLUDGE PRODUCT RECYCLING CONCEPT (KREPRO)



Recyclable products:

- Biofuel
- Precipitant
- Phosphorous
- Carbon source for N-removal

Removed :

- Pathogens
- Heavy metals

KREPRO PROCESS CONDITIONS

- Acidification
  - pH = 1-2 – most inorganic salts dissolve
- Hydrolysis:
  - T = 140 ºC, 3-4 bars, 30-40 min, COD hydrolysation: 40%
- Separation of organic fraction :
  - DS in cake : 45-55 %
- Energy content of organic fraction:
  - 6-8 MJ/kg
- Ferri-phosphate step:
  - pH = 3, DS in separated cake: 35 %, P-content: 15 %
- Recycled stream containing carbon source and coagulant (Fe):
  - Soluble COD: 10-15 kg COD/m^3, Fe : 6-7 kg/m^3
- Sludge reduction:
  - Mass: 60 %, Volume: 80 %

THE KREPRO FRACTIONS I

THE "BIOFUEL" FRACTION:

- 45-55 % DS (30 % ash)
- Heat value: 6-8 MJ/kg equal to wood-chips
- Risk of slagging and fouling in furnace lower than with wood chips
- Heavy metals < max value for use on land
- N-content higher than wood chips, i.e. higher NO_x-emissions

THE KREPRO FRACTIONS II

THE PHOSPHATE FRACTION:

- Form: Ferric phosphate
- 35 % DS (15 % as P)
- Heavy metals and org. micropoll: very low < commercial fertilizer
- Ferric phosphate not water soluble but 100 % citrate soluble
- Growth tests: Close to equally good as commercial fertilizer (4-5 % less yield)

THE KREPRO FRACTIONS III

THE RECYCLED PRECIPITANT:

- Present in recycled liquid phase
- $Iron_{II}$ content: 6-7 kg Fe /m^3
- Sufficient for P-precipitation i.e. all iron may be added to sludge treatment process
- Alternative to recycle: Precipitation as iron-hydroxide separated and recovered
- Residual metal may be separated by sulfide addition and metal sulfide precipitation

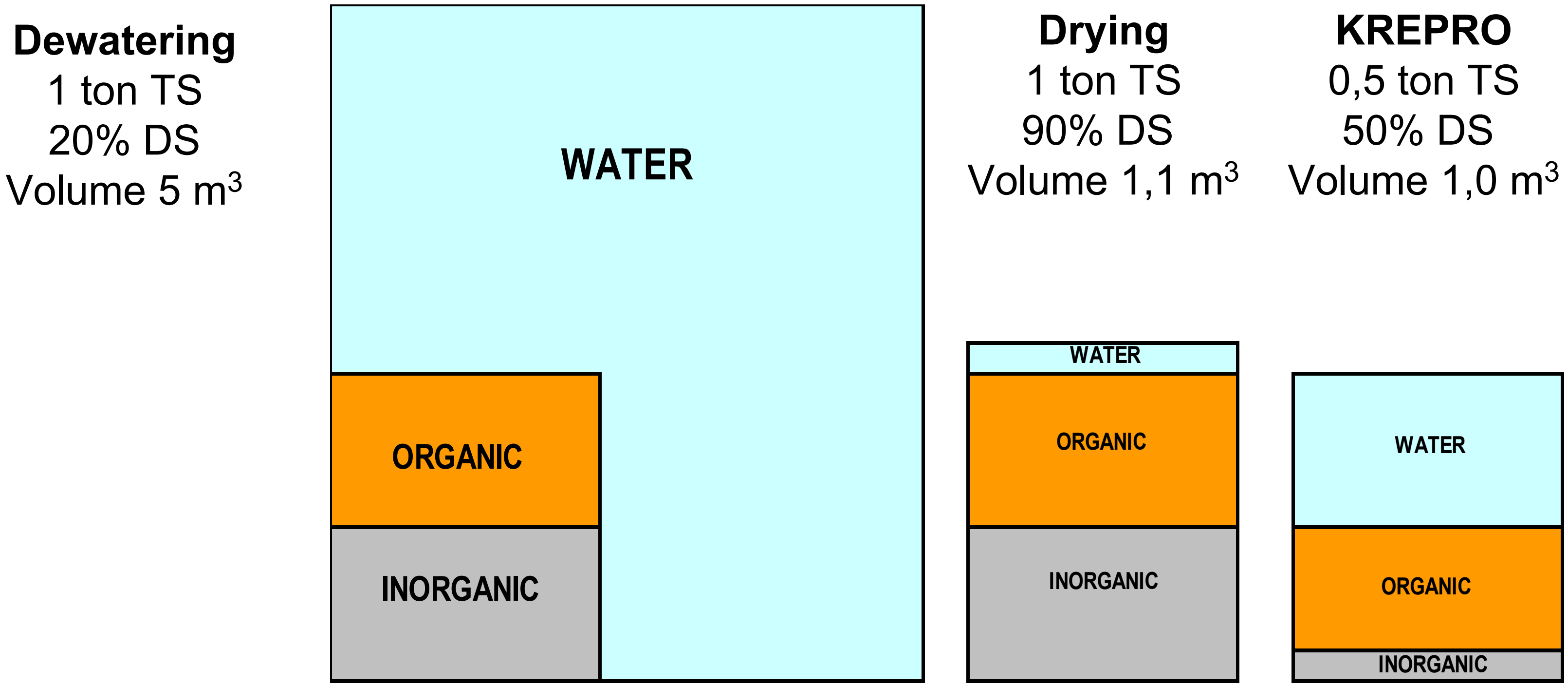
THE KREPRO FRACTIONS IV

THE RECYCLED CARBON SOURCE

- May be used in order to enhance biological N- and P-removal
- Contains high concentration of easily biodegradble COD
- Contains also ammonium, however, that adds to N-load
- May be recycled within the plant – not externally
- May alternatively be co-digested with sludge to increase biogas

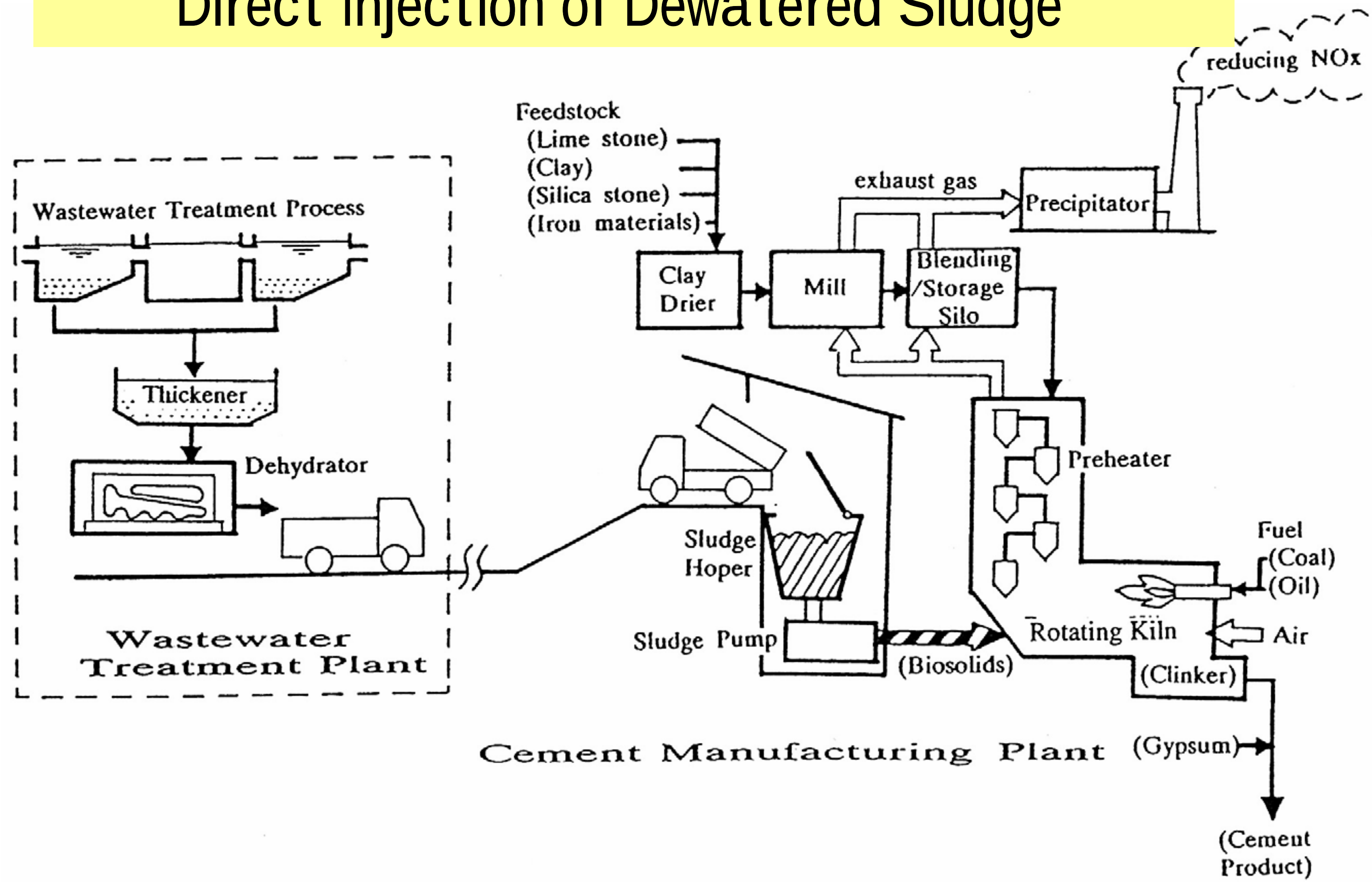
Parameter	Unit	Digested	Undigested
$COD_{filtrered}$	mg/l	13000	11000
VFA	mg/l	1100	1800
Tot $N_{filtered}$	mg/l	1600	820
COD/N	g/g	8.1	13.4
Direct degradable COD	%	5.5	12.7
Denitrification rate (compared to acetate)	mg NO_x-N/ g VSS*h	1.9-2.2 (2.8)	1.9-3.4 (3.8)

WATER, ORGANIC AND INORGANIC FRACTIONS FOR DIFFERENTLY TREATED SLUDGES

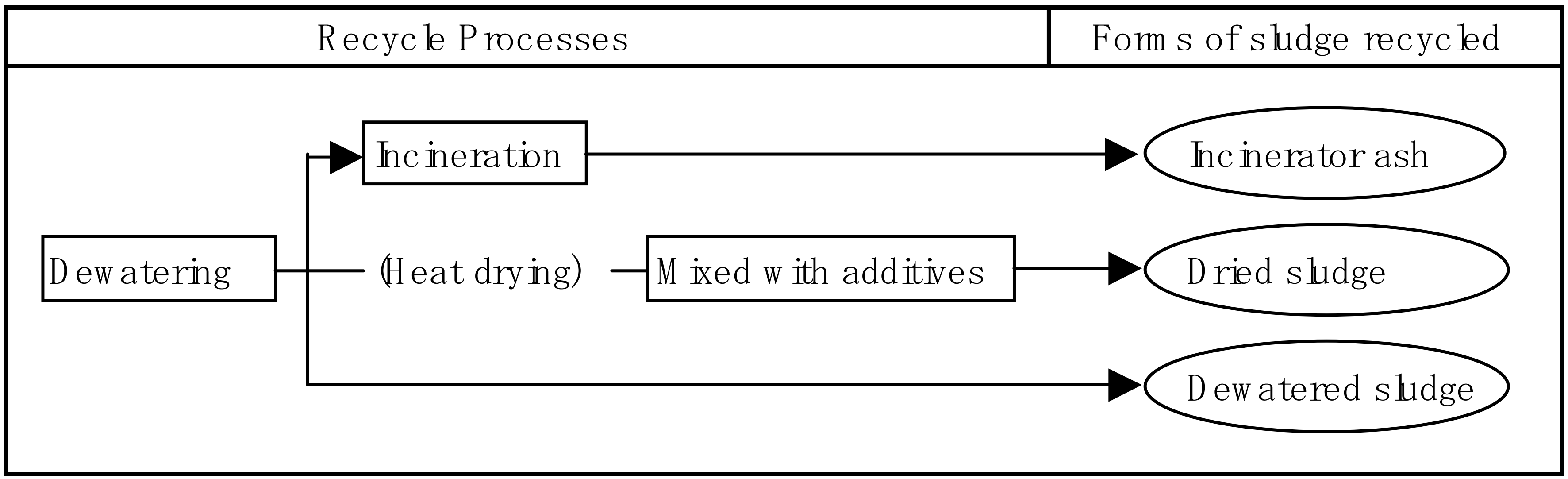


Even if KREPRO is primarily a recycling method, it also reduces the amount of final sludge to be disposed of - if not recycled

Portland Cement Manufacturing Processes and Direct Injection of Dewatered Sludge



Pretreatment of Sludge Before Addition



CONCLUSIONS

1. Since depositing (land filling) is to be phased out as an alternative sludge disposal method, there are principally two main disposal options left; 1) Use of sludge on land, 2) Productification of sludge
2. Most experts agree that use of sludge on land is the most sustainable alternative. This requires treatment, particularly disinfection and strict regulations with respect to quality of sludge to be used. There are good treatment alternatives available based on stabilization and disinfection.
3. Among the "productification" strategies the use of "bio-soils" (i.e. growth soils with sludge a central ingredient) on green areas has a great potential as an alternative to direct use of sludge on farmland
4. Another "productification" strategy is based on recycling of products from sludge that can either be used in-plant or sold to the open market The KREPRO process is one example of such a recycle system.

International Water Association

NTNU
Norwegian University of Science and Technology

See you in Norway in June 2003 !!!

IWA Specialist Group on Sludge Management

INTERNATIONAL CONFERENCE

1. ANNOUNCEMENT

BIOSOLIDS 2003
Wastewater Sludge as a Resource

23-25 June, 2003

Norwegian University of Science and Technology (NTNU)
Trondheim, Norway