Bio-oxidation systems for landfill gas:

2. Overview of full-scale engineered systems, Danish Biocover Initiative

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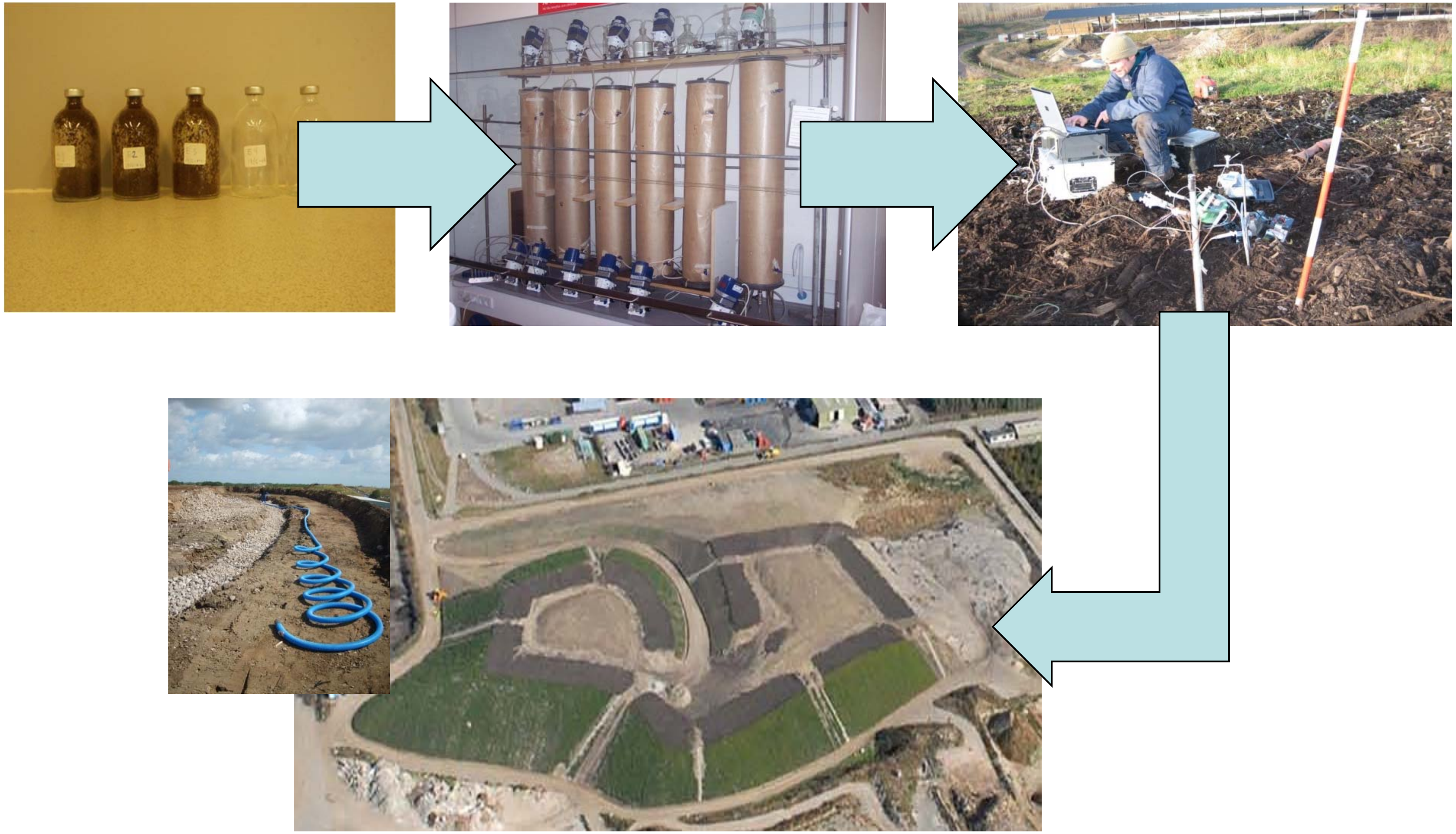
Acknowledgement

- Professor Charlotte Scheutz
- Post doc Anders M. Fredenslund
- Post doc Jacob Mønster
- And several other students

Outline for presentation

- From lab tests to full-scale implementation
- Types of bio-oxidation systems – more details
- Overview – biooxidation systems
- Danish full-scale experiences
- Going to full scale – major issues
  - Systematic approach
  - Documentation on system performance
  - Determining representative methane oxidation capacity of suitable materials
  - Good environmental conditions for the methanotrophs
  - Gas distribution
- The Danish biocover initiative – procedures and status
- Conclusions

From lab batch to innovative full scale biocover system – a focused long term research task

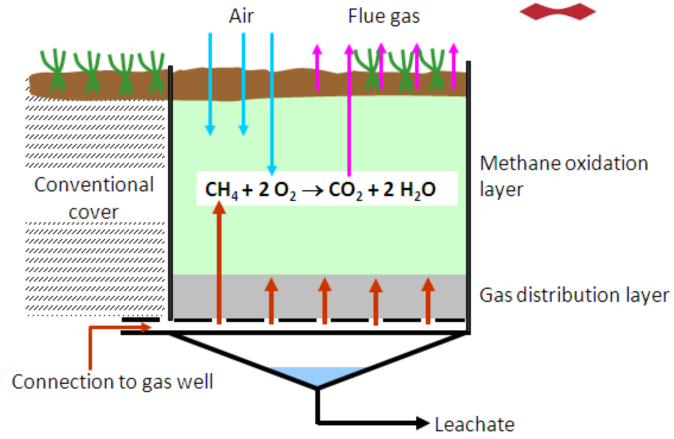


Bio-oxidation systems

Filter

- Landfills with gas collection system, active or passive (Streese & Stegmann, 2003; Gebert & Gröngröft, 2006)
- Stable exhausts from animal husbandry (Melse & van der Werf, 2005; BiMoLa)
- Manure storage (Oonk & Koopmans, 2012)
- Coal mine ventilation (Du Plessis et al., 2003)

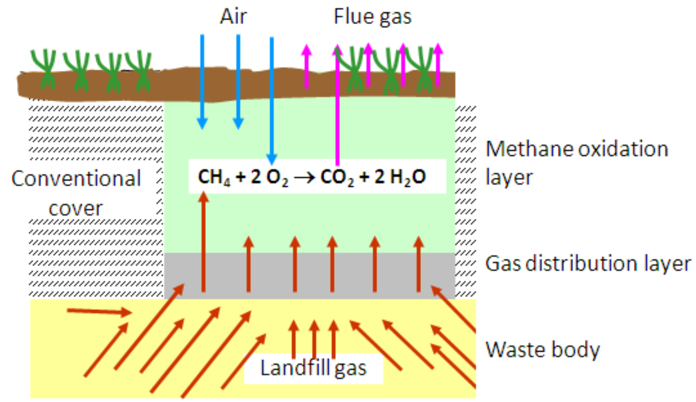
High load, but controllable



Window

- Landfills without gas collection and surface lining (Pedersen et al., 2010)
- Remediation of emission hotspots on old non-sanitary landfills (Röwer et al., 2012)

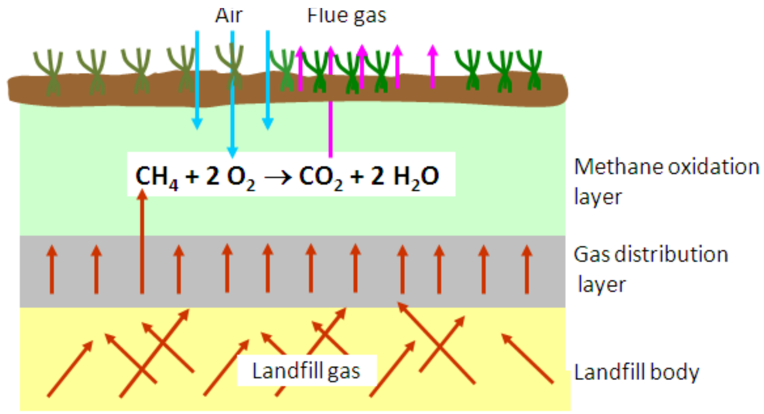
Lower load, uncontrollable



Cover

- Landfills with or without gas collection and surface lining (Huber-Humer et al., 2008; Geck et al., 2013)

Low load, uncontrollable



TU Delft

DTU

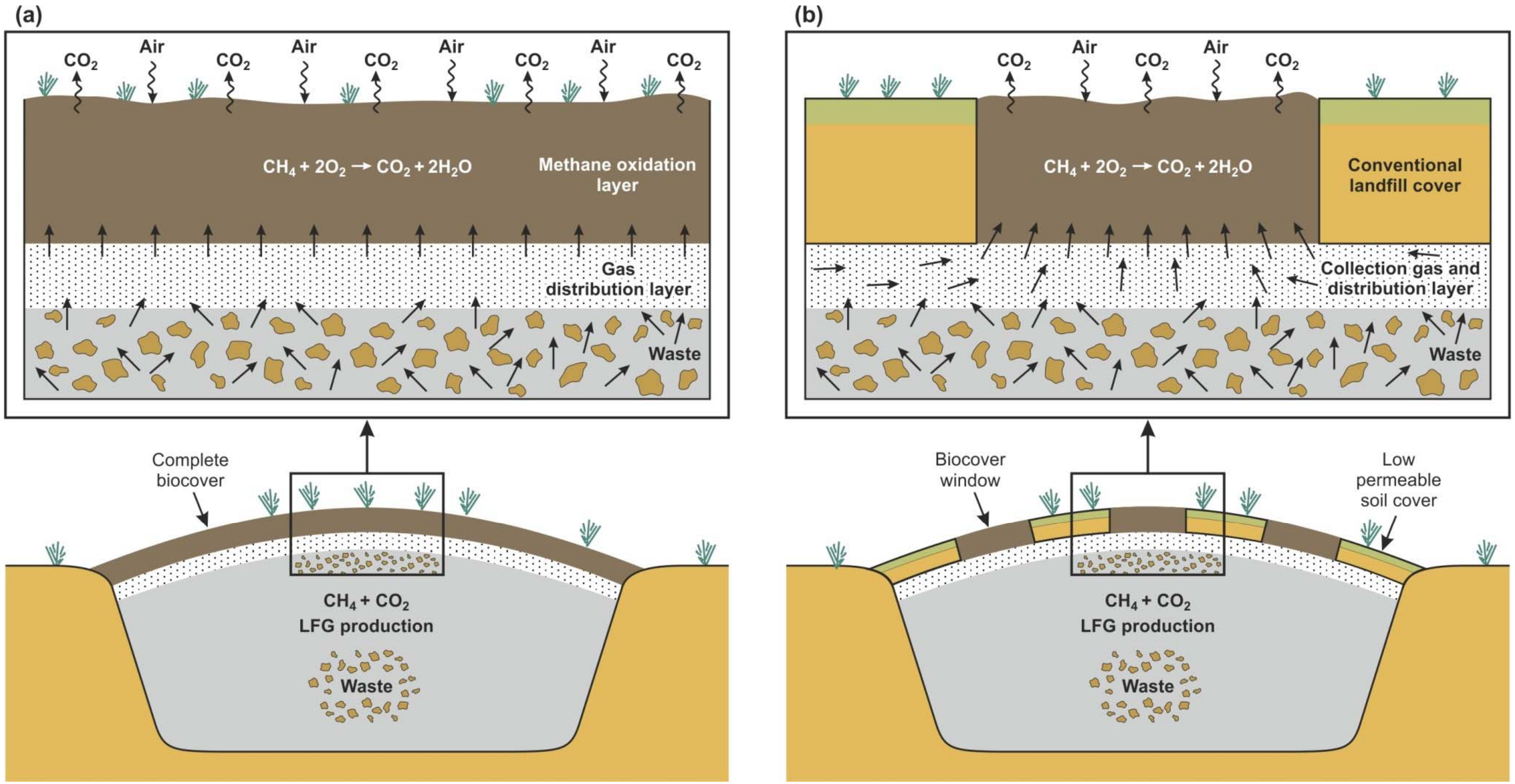
Bio-oxidation in Landfill Gas Management

Scenario	Description
1	No gas collection system (GCS) is in place, the LFG generation is modest. Installation of a GCS and a gas engine not cost-efficient, but LFG emission is regarded as above legal limits.
2	A GCS is in place. The gas engine is old with high running maintenance costs. A replacement of the gas engine is considered non-cost-efficient.
3	A GCS and a gas flaring system is in place. The flares have difficulties to run without the use of supporting fuel, but LFG emission is regarded as above legal limits.

Types of Bio-oxidation Systems

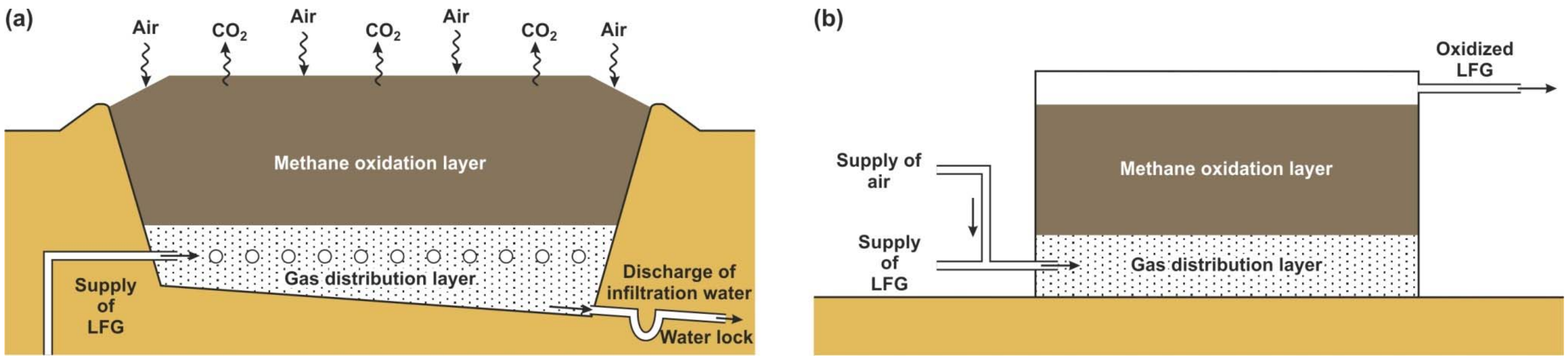
Type - passive	Description
Full surface biocover (Sc 1)	The whole landfill area is covered with a homogenous layer of bioactive coarse materials (such as a coarse soil or compost)
Biowindow system (Sc 1)	A system incorporating the presence of an existing, low permeable soil cover. Areas of the existing cover is replaced by gas permeable, bioactive materials (such as a coarse soil or compost) underlain by a gas distribution layer of gravel. Gas is loaded passively to the biowindows.
Biofilter, open bed (Sc 2 & 3)	A system consisting of a volume of bioactive materials where LFG is fed from below through a gas distribution layer. Open to the atmosphere so oxygen can diffuse into the bioactive material from above.
Biofilter, closed bed (Sc 2 & 3)	A system consisting of a volume of bioactive materials where LFG is fed from below/above through a gas distribution layer. Closed to the atmosphere (for instance in a container) so oxygen is to be part of the loading gas.

Full surface biocover vs biowindow system



Biofilters, open and closed bed

- Methane oxidation filter treating extracted gas either passively or actively

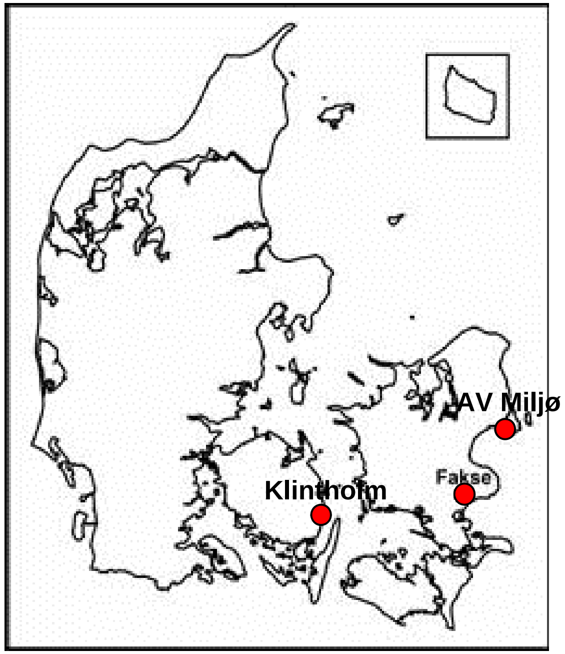


Established Bio-oxidation Systems - a global overview

- In total 22 cases reported in open literature – 9 in full-scale – 13 in pilot scale
- Additional cases exists with less documentation (gray literature)
- Most systems use compost
- Six full surface biocover (Aikkala, Finland and sites in Austria)
- Only the Fakse and the Klintholm cases uses the TEMBA approach (TEMBA = Total Emission Measurement Before and After the system establishment)

Established Bio-oxidation Systems – Danish Experiences

- Fakse Landfill (2006-2008)
  - First fully documented site
  - Biowindows system, passive, compost based
  - Described in papers in Waste Management (2011)
- Klintholm Landfill (2008-2011)
  - Biofilter/Biowindow system with constructed gas collection system, passive, compost based
  - Described in Waste Management (2014)
- AV Miljø Landfill (2011-2014)
  - Pilot scale, active biofilter system, compost based
  - Gas collected from 3 leachate wells
  - Elevated oxygen content in gas loaded to the system
  - Described in Waste Management (2017)



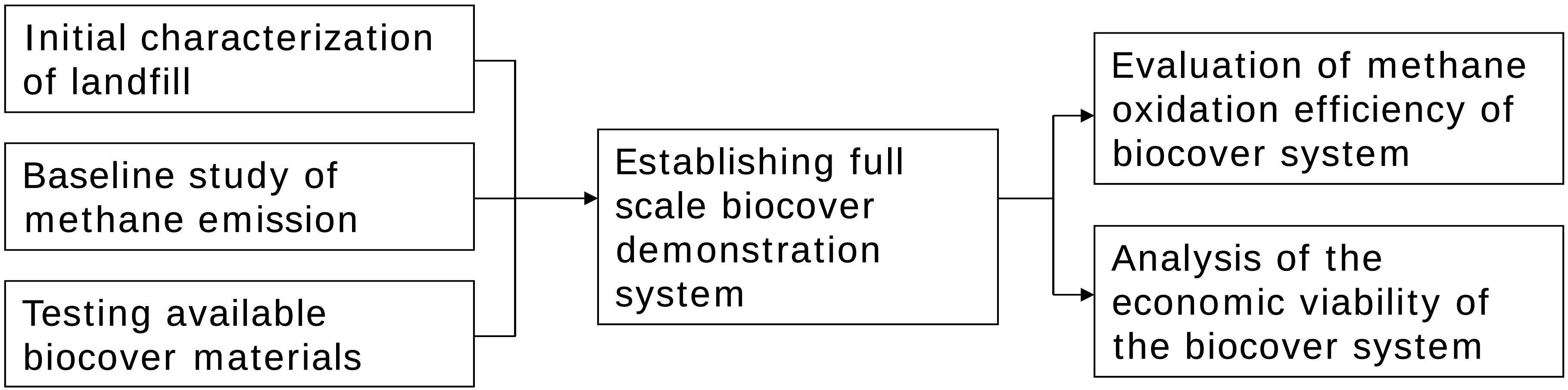
Advantages and disadvantages of using compost as methane oxidation material

<table>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td colspan="2">Compost</td></tr>
<tr><td>
Has a large surface area that supports bacterial growth
Contains nutrients
With the right sieve, high porosity is acheived, (→ relatively high water content and still high gas conductivity and gas diffusivity)
With the right sieve a sufficiently high conductivity is achieved (→ gas can be transported upward and infiltrating water can be transported downward)
Has a good ability to avoid drying due to its good water retention ability
Has good thermal insulation (→ can hold on the heat produced by respiration and methane oxidation or applied from the hot waste body underneath)
Often produced in large quantities at the composting facility located next to the landfill (→ can be obtained cheaply)
</td><td>
Compost is an unstable material (→ the continuing maturation process can potentially destroy the good qualities in long term)
Local limitations in the appearance of suitable compost materials (→ higher prices)
Increased demand for compost for soil improvement? (→ higher prices)
May have excessive oxygen consumption (respiration) (→ anaerobic conditions in methane oxidation layer)
Significant turnover of organic material (→ essential settlement of the methane oxidation layer)
The compost material potential needs replacement (or supplemented) with time
</td></tr>
</table>

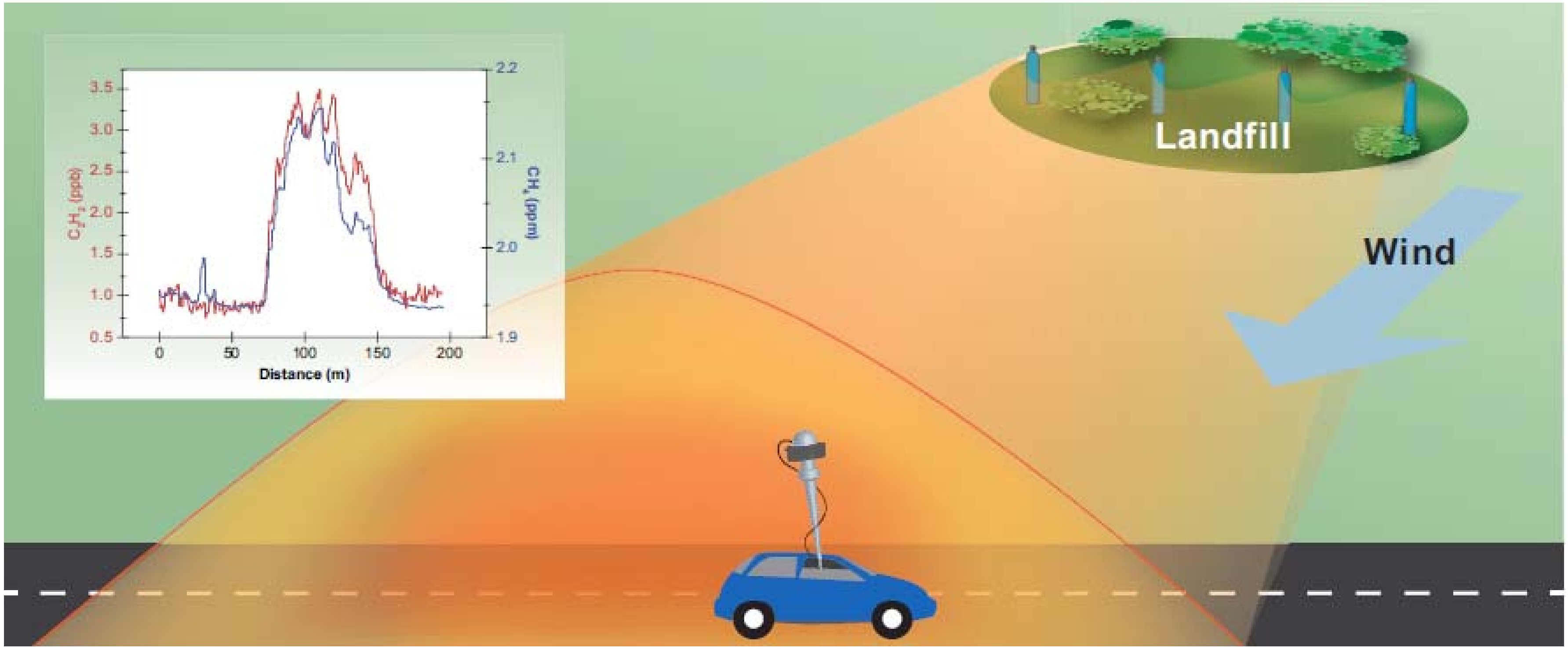
Going to full scale – some major issues

1. Use a systematic approach – the protocol
2. Performing full-scale efficiency evaluation of the bio-oxidation system – the TEMBA approach
3. Determine a realistic methane oxidation efficiency (in grams $CH_4/m^2 \cdot day$) for the full-scale scenario
4. Maintaining good environmental conditions for the methane oxidation process (water, temperature, oxygen, etc) – in all climatic conditions – and also in long term
5. Obtain even gas distribution to the bio-active layer – avoiding hot spots

1. Use a systematic approach – the protocol



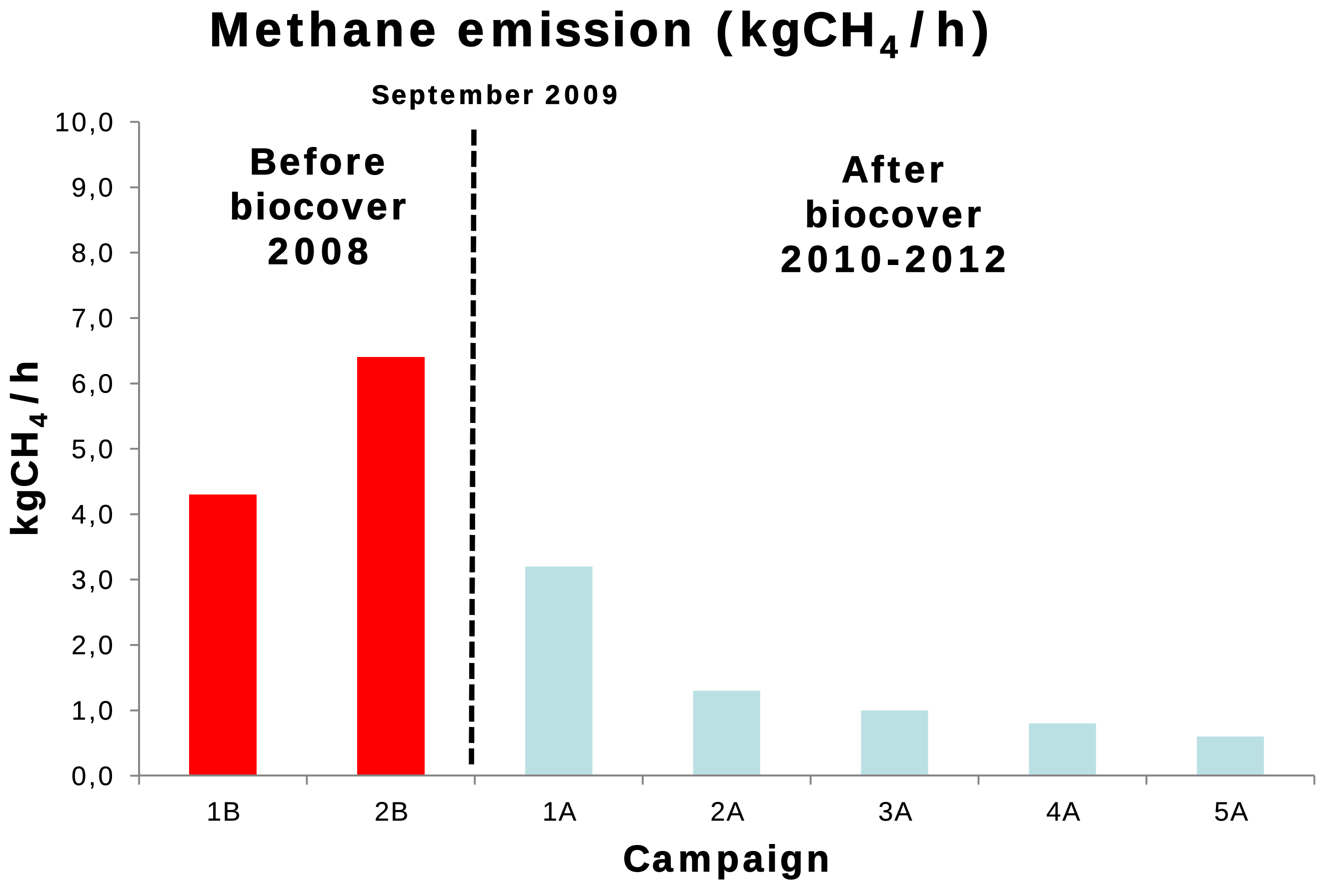
2. Performing full-scale efficiency evaluation of the bio-oxidation system – the TEMBA approach using the dynamic tracer dispersion method



$$E_{gas} = Q_{tracer} \cdot \frac{\int_{Plumeend\,1}^{Plumeend\,2} C_{gas}\,dx}{\int_{Plumeend\,1}^{Plumeend\,2} C_{tracer}\,dx} \cdot \frac{MW_{gas}}{MW_{tracer}}$$

- Tracer gas with long atmospheric lifetime
- Good/stable wind & road conditions
- Sensitive analytical instrument

TEMBA: Total Emission Measurement Before and After – Klintholm landfill



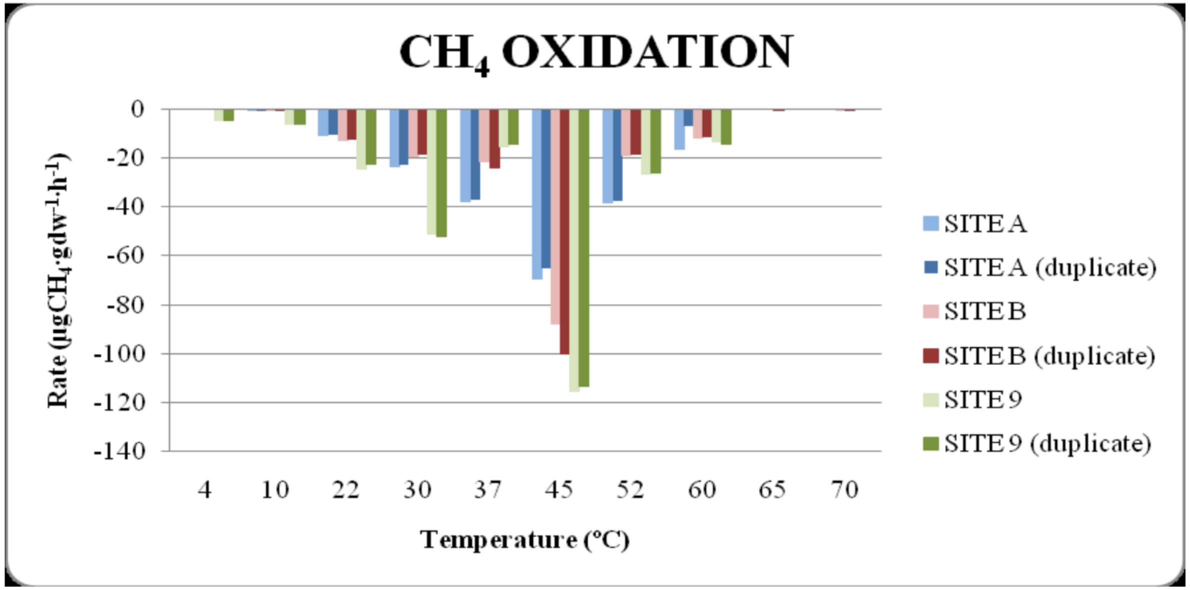
Measured efficiency: 83%

3. Determine a realistic methane oxidation efficiency (in grams CH_4 / m^2 · day) for full-scale scenarios

- An estimated efficiency is needed for selecting an appropiate footage area of biowindows/biofilters
- Lab determined efficiencies in column tests are in the range 50 – 400 grams CH_4/m^2 · day
- Do we need to use safety factors for upscaling to field scale (respecting spatial heterogeneous gas loads) ?
- Too few field experiences are obtained to give a full answer….

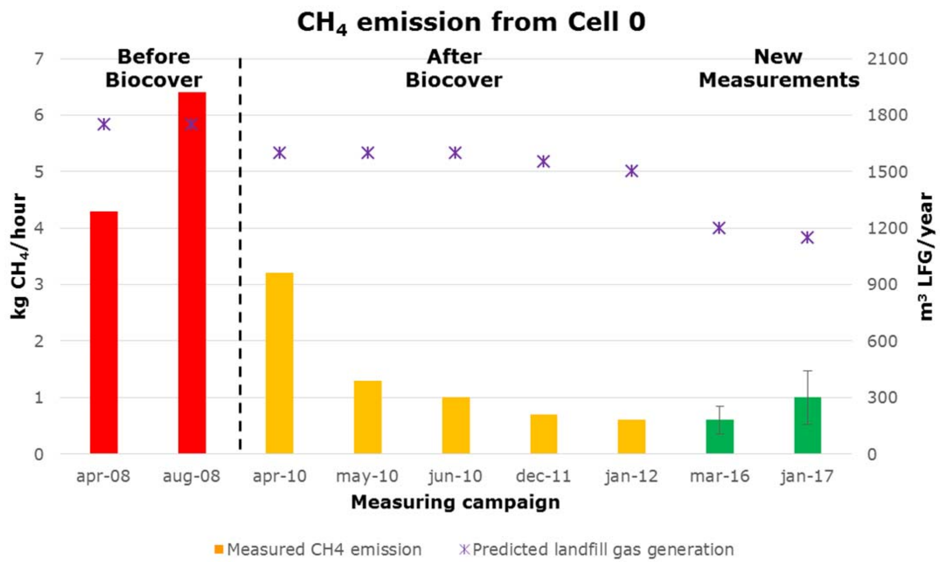
4. Maintaining good environmental conditions for the methane oxidation process - temperature

- Laboratory determined temperature optimum:
  - 25-35 ° C for soil
  - 45-55 ° C for compost
- High temperatures was observed in all 3 Danish sites at all seasons (even strong winters) (>25-30° C at depth > 40 cm)
- Main reasons are heat from methane oxidation and compost respiration



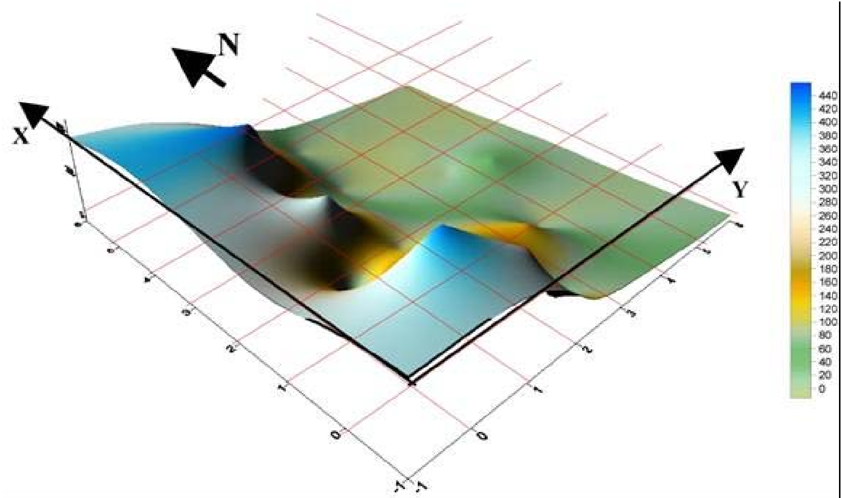
4. Maintaining good environmental conditions for the methane oxidation process – long term

- Klintholm site revisited in 2016 - 6-7 years after establishment
  - Still low total emission of CH_4
  - Gas concentration profiles and CH_4 oxidation tests suggest CH_4 oxidation in the MOL
  - Oxygen was able to penetrate the entire MOL and into the GDL
  - Still elevated temperatures
  - Lab batch test give MO rates comparable to the initial rates
  - Imperfect distribution of landfill gas – hotspots still occur
  - **The biocover system functioned as intended after 6-7 years**
  - **No maintenance seems required (Danish conditions)**



5. Obtain even gas distribution to the bio-active layer – avoiding hot spots - 1. try

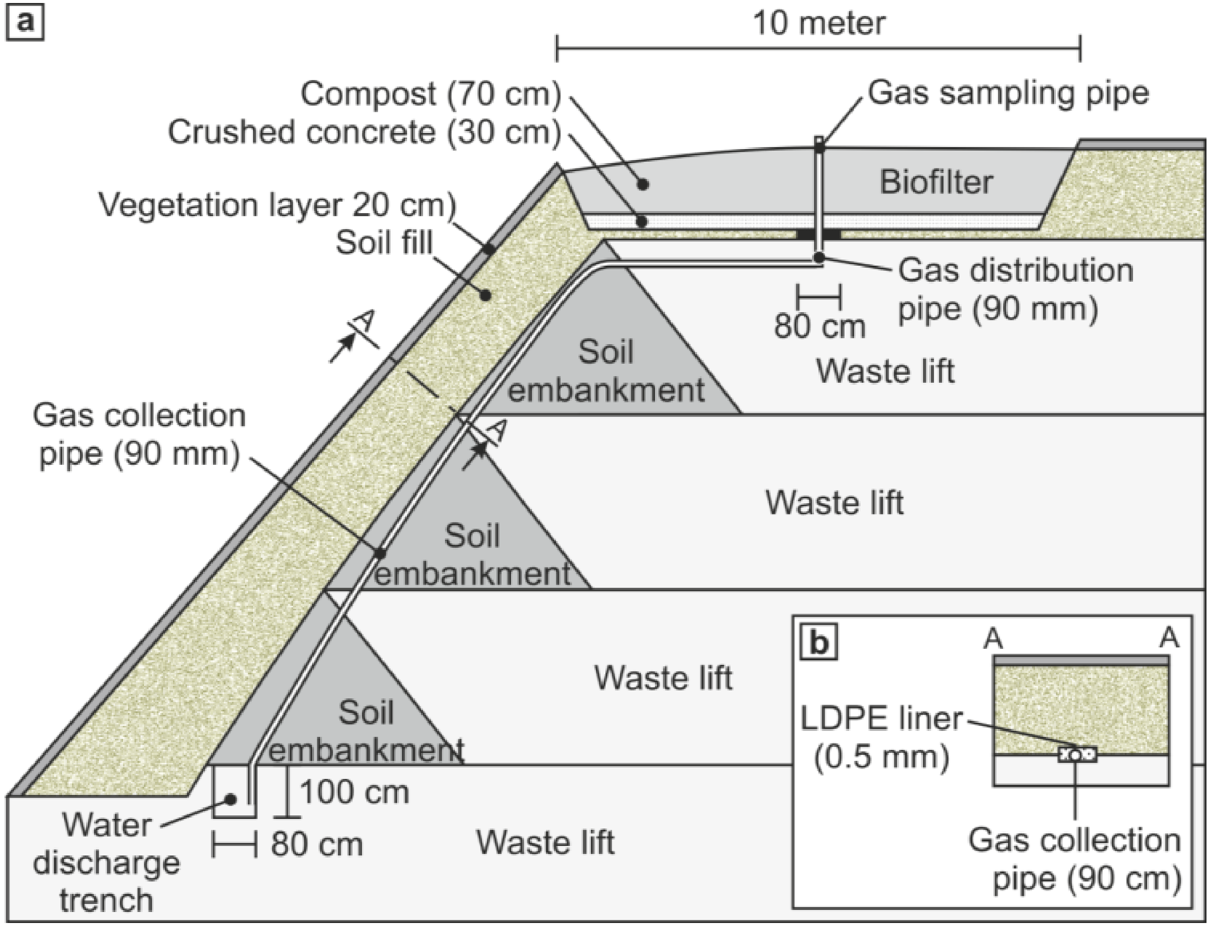
Fakse Landfill



Fakse: Lateral gas load to biowindow creates hot spot area

Overall CH_4 oxidation ~ 30 %

5. Obtain even gas distribution to the bio-active layer – avoiding hot spots – 2. try



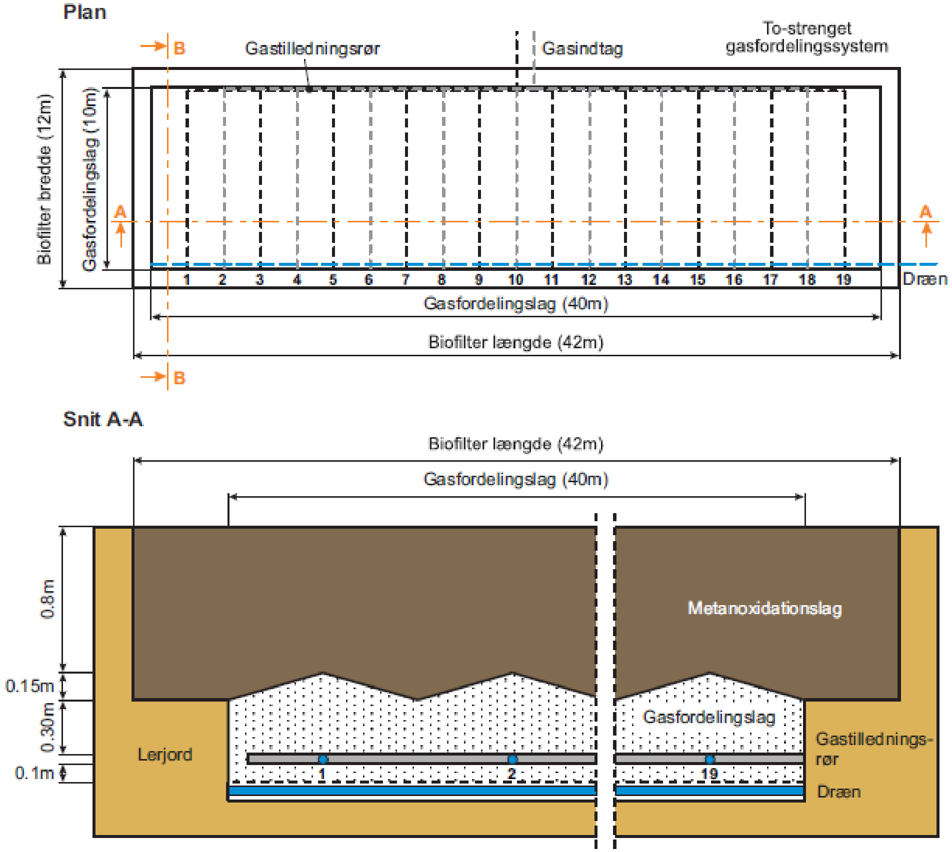
Klintholm Landfill

5. Obtain even gas distribution to the bio-active layer – avoiding hot spots – 2. try

Klintholm Landfill

Overall CH_4 oxidation ~ 85 %

5. Obtain even gas distribution to the bio-active layer – avoiding hot spots – 3. try



From innovation to national implementation

- The Danish Government has initiated an emission reduction program on old landfills based on our bio-oxidation technology – ”The Danish Biocover Initiative” - as one way to reduce national greenhouse gas emissions
  - Goal: establishment of biocover systems on up to 100 sites
  - Frame: 25 mill. € over 4 years as state support to projects
  - The Danish EPA is managing the program
  - We are scientific consultants on the program


Miljø- og Fødevareministeriet
Miljøstyrelsen

Luft & Støj | Erhverv | Kemi | Affald & Jord

ffald > Deponering > Biocover-tilskudsordning

Tilskudsordning for biocover

Der er afsat 178 mio. kr. i tilskudsmidler til etablering af biocoverløsninger på deponeringsanlæg og lossepladser frem til 2020. Formålet er at reducere drivhusgas-udledningen ved at omdanne metan fra affaldsnedbrydningen til CO_2.

Som et led i Danmarks målsætning om at reducere udledningen af drivhusgasser er det besluttet at finansiere etablering af såkaldte biocovers på danske deponeringsanlæg og lossepladser, hvorfra der udledes metan fra affaldsnedbrydningen. Ved biocoverløsninger omdannes metanen til CO_2, som er en ca. 25 gange mildere drivhusgas. Miljøstyrelsen står for udformning og administration af tilskudsordningen, og på undersiderne kan du kan læse mere om biocover-teknologien og opbygningen af tilskudsordningen.

Senest opdateret 26-09-2016

- Biocover-teknologien
- Ordningens opbygning
- Hvad dækker tilskuddet
- Værd at vide inden ansøgning
- Ansøgning om tilskud
- Vejledning til gennemførelse
- Afrapportering og dokumentationskrav
- Udbetaling af tilskud
- Erfaringer der gør os klogere
- Bag om ordningen
- FAQ
- Fremtidsperspektiver

Kontakt
biocover@mst.dk

Nyheder:
Retningslinjer for test af metanoxiderende materialer
Ved planlægning og gennemførelse af et biocoverprojekt skal retningslinjerne for test af det ønskede metanoxiderende materiale følges. Læs mere her .

Screening af regionernes gamle lossepladser
Hvis du overjvejer at søge tilskud til et projekt på en af landets gamle lossepladser, bor du orientere dig her .

The Danish Biocover Initiative - procedure

- Executive order to follow for be granted support
- Baseline study first granted
- Total emission >6 kg/h then support for Conceptual design is granted
- If conceptual design is accepted money for detailed design and support for construction is granted

BEK nr 752 af 21/06/2016 (Gældende)	Udskriftsdato: 27. september 2017
Ministerium: Miljø- og Fødevareministeriet	**Senere ændringer til forskriften**
Journalnummer: Miljø- og Fødevaremin., Miljøstyrelsen, j.nr. MST-729-00086	Ingen

Bekendtgørelse om tilskud til etablering af biocover på deponeringsanlæg og lossepladser

I medfør af tekstanmærkning nr. 106 ad 24.55.07. til § 24 på finansloven for 2016 fastsættes:

Kapitel 1

Bekendtgørelsens område og definitioner

§ 1. Bekendtgørelsen fastsætter rammerne for tildeling af tilskud fra tilskudsordningen til etablering af biocover på deponeringsanlæg og lossepladser.

§ 2. I denne bekendtgørelse forstås ved:

1) Ansøger: Region på vegne af ejer af nedlukkede lossepladser, der er kortlagt efter jordforureningsloven, eller ejer af deponeringsanlæg eller losseplads.
2) Baselineundersøgelse: En undersøgelse, som udføres på deponeringsanlægget eller lossepladsen for at vurdere potentialet for etablering af et biocoversystem og med henblik på at udarbejde en projektbeskrivelse til ansøgning om et biocoverprojekt. Baselineundersøgelsen fastlægger den samlede metanemission via to totalmålinger, samt emissionsmønstret gennem en overfladescreening.
3) Biocover: System til reduktion af metanemission fra et deponeringsanlæg eller en losseplads, som baserer sig på biologisk metanoxidation ved hjælp af kompost eller tilsvarende materiale, der understøtter metanoxiderende mikroorganismer.
4) Biocoverprojekt: Det samlede projekt efter baselineundersøgelsen, herunder detailprojektering, etablering af biocoversystem, opfølgende måling, eventuel udbedring, monitering og eventuel vedligeholdelse indtil sidste tilskudsdækkede monitering,
5) Deponeringsanlæg: Som defineret i bekendtgørelse om deponeringsanlæg.
6) Losseplads: En samlebetegnelse for lossepladser, deponier, fyldpladser, affaldsdepoter eller lignende anlæg, som ikke er omfattet af definitionen af deponeringsanlæg.
7) Metanoxidationsmateriale: Materiale, for eksempel kompost, der skal understøtte biologisk metanoxidation i biocoversystemet.
8) Metanoxidationspotentiale: Metanoxidationsmaterialets potentiale til at understøtte biologisk metanoxidation.
9) Monitering: Bestemmelse af den samlede metanemission fra deponeringsanlægget eller lossepladsen ved udførelse af en totalmåling.
10) Opfølgende måling: Bestemmelse af metanemissionen fra deponeringsanlægget eller lossepladsen efter etablering af biocover, ved udførelse af en totalmåling og en overfladescreening.
11) Overfladescreening: En kortlægning af deponeringsanlæggets eller lossepladsens metanemission med en metode, som måler metanemissionens fordeling over den relevante del af deponeringsanlæggets eller lossepladsens overflade og installationer.
12) Totalmåling: Måling af den totale metanemission med en metode, som fra afstand integrerer den samlede metanemission fra den relevante del af deponeringsanlægget eller lossepladsen.

1

Guidance : The biocover handbook – 70 pages

- List of content
- Summary – in English
- Introduction
- Landfill gas mitigation – an overview
- Landfill gas mitigation by bio-oxidation systems
  - Methane oxidizing microorganisms
  - The methane oxidation process
  - Controlling environmental factors
  - Observed methane oxidation rates
  - Types of biocover systems
  - National and international field experiences
  - Important factors for biocover functionality
- Protocol for establishing and monitoring of biocover-systems
- Initial site characterization
- Baseline study
- Testing and selecting biocover materials
- Design and establishment of biocover systems
- Evaluation of biocover mitigation efficiency
- Economical evaluation
- References

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Miljø- og Fødevareministeriet
Miljøstyrelsen

Etablering og monitering af biocoversystemer på affaldsdeponerings-anlæg

Vidensopsamling

Miljøprojekt nr. 1817, 2016

Design

- Test of material for MOL (compost)
  - Batch test
    - MO > 20µg CH_4/g material (DW) and hour
    - Respiration <48 µgO_2/g material (DW) and hour
- Project on Compost catalogue
  - Result ”Normal” compost materials (garden/yard waste based) do not need testing

- Biocover layers
  - GDL recommended 30 cm
  - MOL recommended 80-100 cm

Dimensioning

- Total CH_4 emission measured in baseline study (kg/h)
- Emission from each subsource measured/estimated (kg/h)
- MO capacity: 50 gCH_4/m^2 and day
- Area of each sub system estimated

Status of the biocover initiative

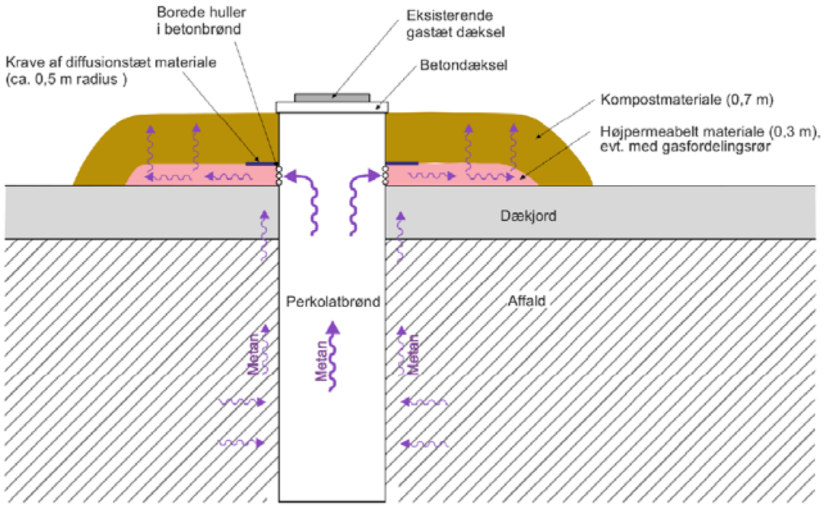
- The initiative has been delayed

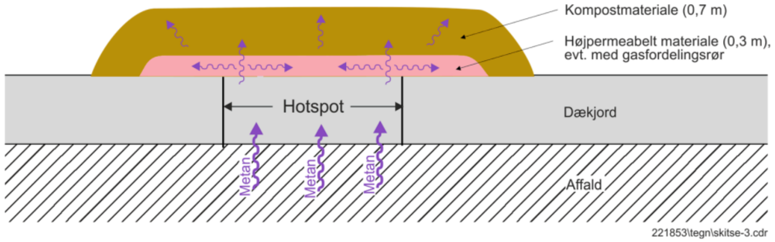
Status as of March 2018:

- 5 pilotstudies initiated (to gain more detailed experiences)
- 89 proposals received for obtaining financial support
- 49 baseline studies granted (39 finalized)
- 16 conceptual designs received
- The first biocover systems soon to be established

General trend of solutions

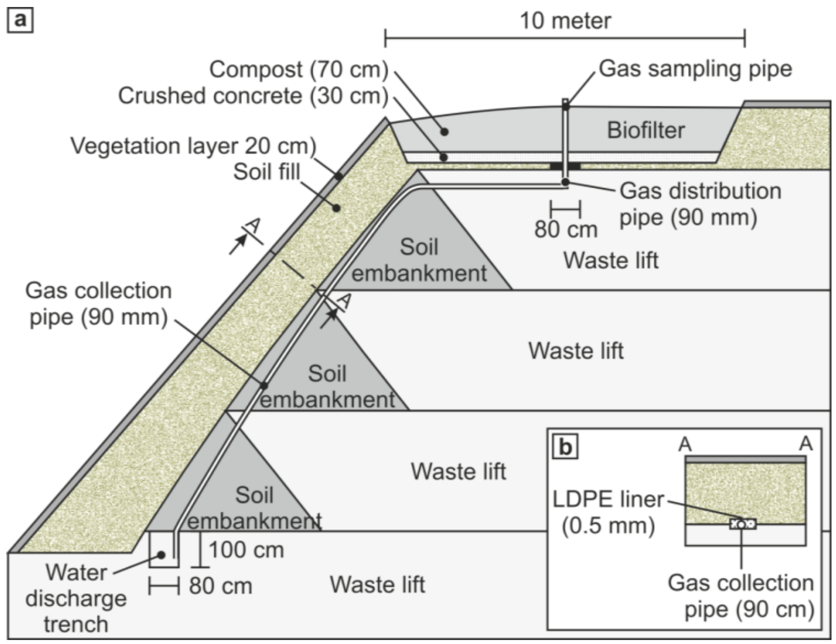
- Combination of filters treating point sources and biowindows treating hot spot areas
- Point sources are mostly leachate collection/inspection wells





General trend of solutions

- Combination of filters treating point sources and biowindows treating hot spot areas
- Point sources are mostly leachate collection/inspection wells
- Many hot spots on slopes – can biowindows be established on slopes?
- Or is the ”Klintholm approach” better?



Conclusions

- Potential of bio-oxidation systems for mitigation of landfill emissions is very high
- Target situations: non-sanitary landfills (hotspot remediation, cover improvement), sanitary landfills at the end of technical gas treatment or with low gas generation potential (MBT, dredged material, mixed waste with low organic content, etc)
- Microbes are naturally occuring, high turnover rates can be reached with a variety of substrates (soil, compost, others)
- Governing factors of the microbial methane oxidation process are known and can be accounted for in the design process

Conclusions, continued

- Upscale is the challenge: We need to work in full-scale to obtain the needed insight
- It is crucial to use a robust performance documentation
- There are still some challenges concerning oxygen control, gas distribution in biocovers, seasonal effects and long term performance
- The Danish Biocover Initiative will hopeful further develop the technology successfully
- Currently also full-scale implementation in several other countries

Selected articles - bio-oxidation systems - DTU

- Cassini, F., Scheutz, C., Skov, B.H., Zishen, M., Kjeldsen, P. (2017). Mitigation of methane emissions in a pilot-scale biocover system at the AV Miljø Landfill, Denmark: 1. System design and gas distribution. *Waste Management,* 63, 213–225*.*
- Scheutz, C., Cassini, F., De Schoenmaeker, J., Kjeldsen, P.(2017). Mitigation of methane emissions in a pilot-scale biocover system at the AV Miljø Landfill, Denmark: 2. Methane oxidation. *Waste Management, 6*3, 203–212.
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- Scheutz, C., Fredenslund, A. M., Chanton, J., Pedersen, G. B., and Kjeldsen, P. (2011): Mitigation of methane emission from Fakse landfill using a biowindow system. *Waste Management*, 31(5), 1018-1028.
- Scheutz, C., Samuelsson, J., Fredenslund, A. M., and Kjeldsen, P. (2011): Quantification of multiple methane emission sources at landfills using a double tracer technique. *Waste Management*, 31(5), 1009-1017.
- Scheutz, C.,. Bogner, J., De Visscher, A., Gebert, J., Hilger, H., Huber-Humer, M., Kjeldsen, P., and Spokas, K. (2009): Processes and technologies for mitigation of landfill gas emissions by microbial methane oxidation. *Waste Management & Research*, 27(5), 409-455.

Thank you for your attention!

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