LANDSS Forum Meeting

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Full scale case studies on
in situ aeration of landfills

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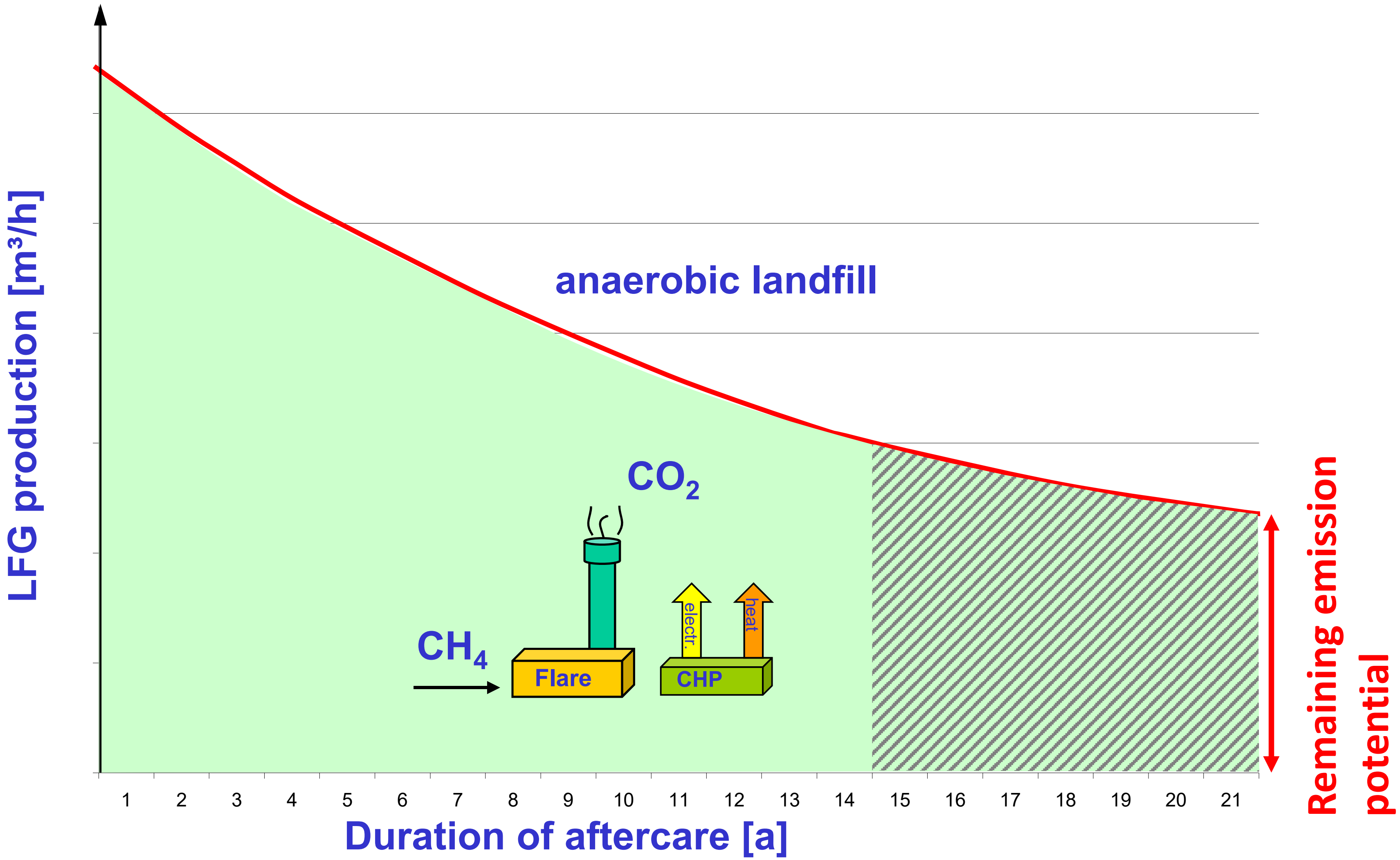
Contents

Problems related to landfills

- **Continuing and long lasting LFG production after completion of LFG to energy (CHP).**

Emissions under anaerobic conditions: LFG



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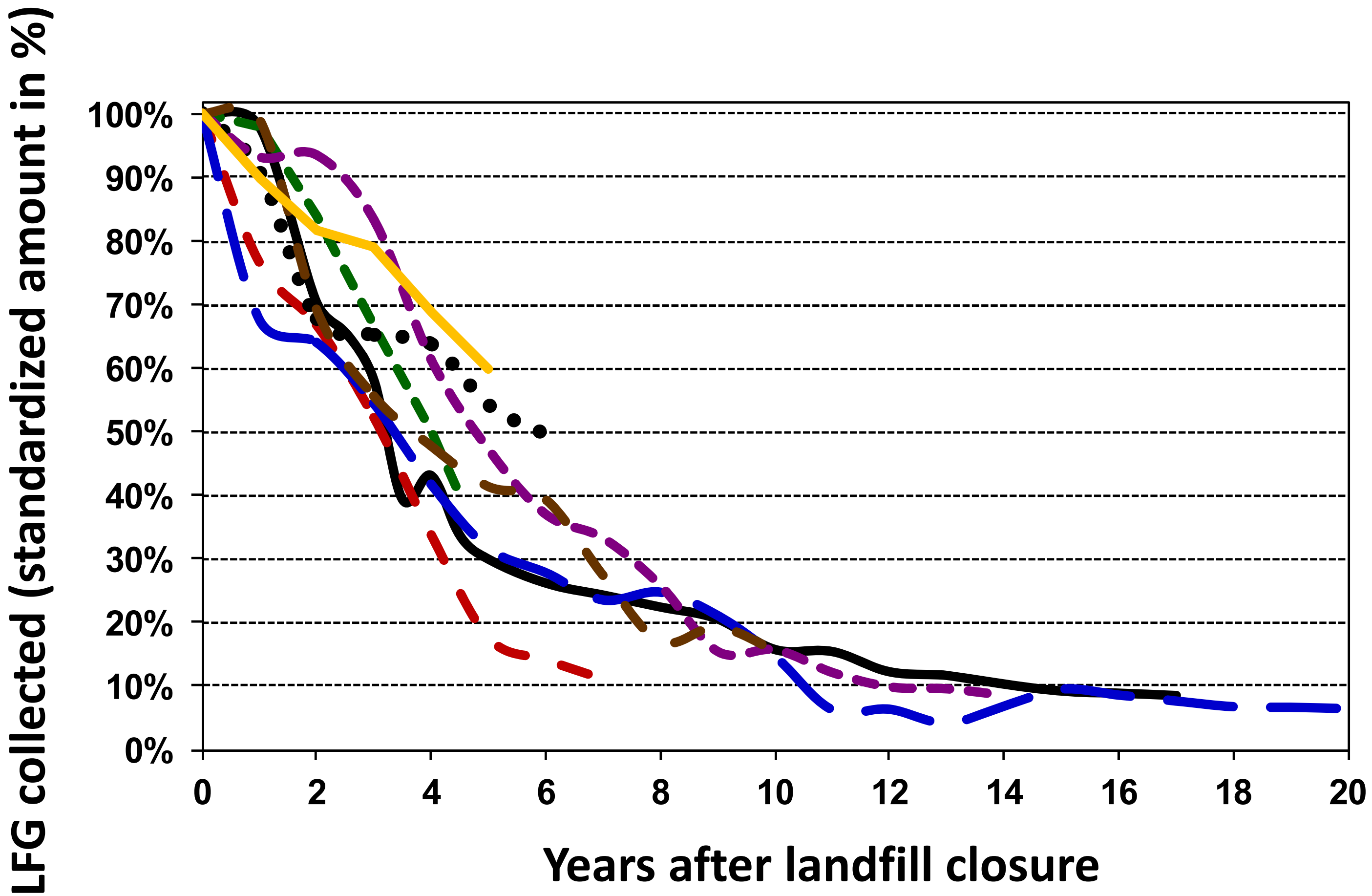
Collected amounts of LFG
(Data from different German landfills)



Source: K.-U. Heyer (IFAS, Hamburg)

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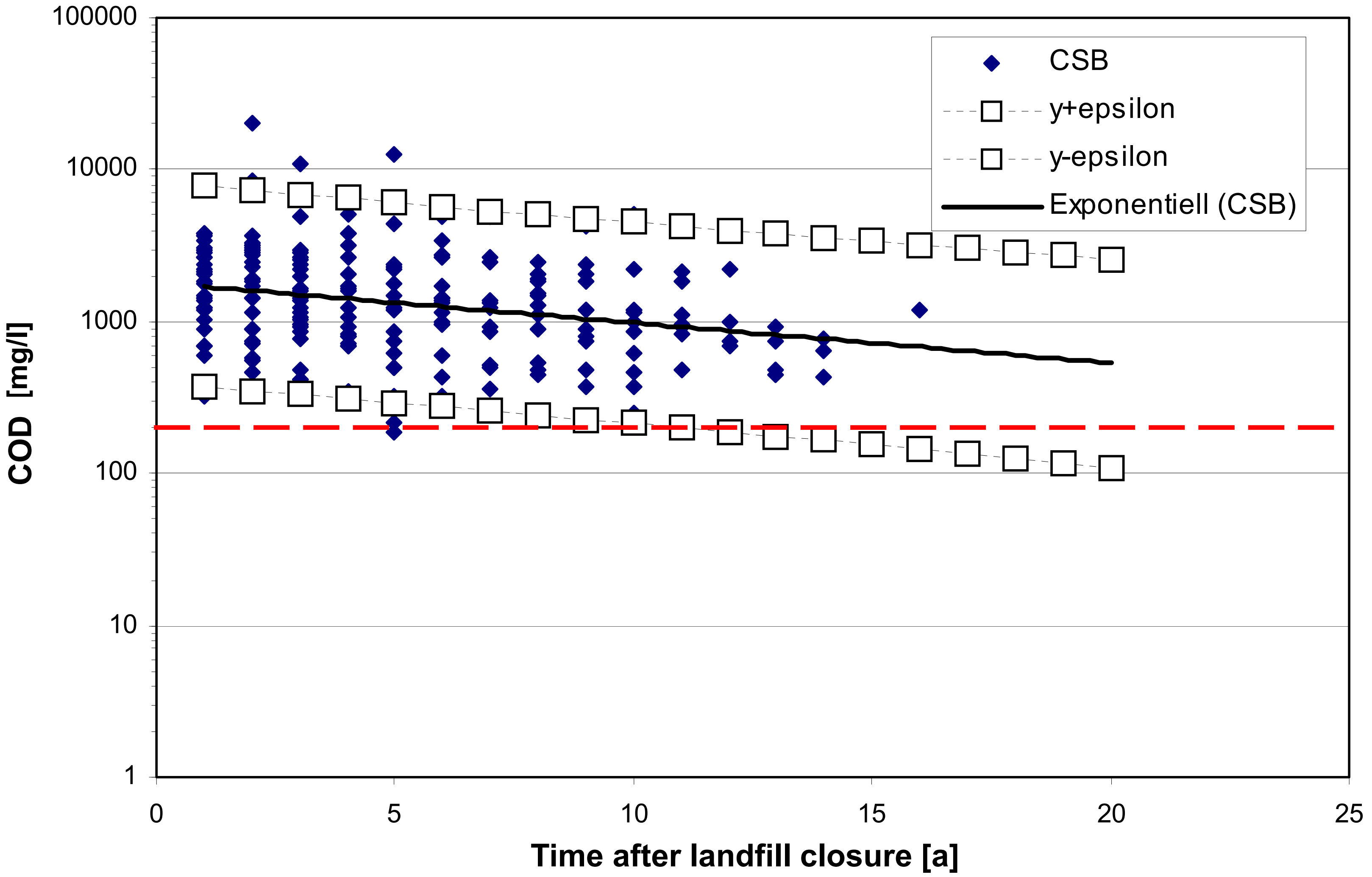
Emissions under anaerobic conditions: Leachate



Source: I. Krümpelbeck (2000); Data from German landfills

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Legal situation

- **According to the German and European legislation, emissions have to be controlled during landfill operation, closure and aftercare.**
- **Release from aftercare (by the competent authority) possible only if the landfill doesn't pose a threat to the environment:**
  - **Insignificant biodegradation processes;**
  - **Leachate quality in accordance with the water regulation for direct discharge (no need for treatment);**
  - **etc.**

➢ **Unpredictable duration of aftercare (responsibility?), high level of uncertainty and eventually very high costs.**

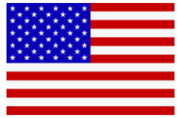
Method of resolution:

- **In situ bio-stabilization (by means of aeration) of the biodegradable organic fraction of landfilled waste:**
  - **Widely and sustainable reduction of the LFG generation potential;**
  - **Acceleration and completion of the main landfill settlements;**
  - **Improvement of the leachate quality (mainly with regard to organic pollutants and ammonia-nitrogen);**
  - ➢ **Creation of a bio-stabilized landfill which requires less intensive and probably shorter aftercare. (German approach)**

What about the motivation to aerate landfills in other countries?

Different motivations for applying LF aeration

- **Earlier recovery of landfill volume**
  - US approach with aerated bioreactor landfills



- **Avoidance of GHG emissions**
  - Applied in the framework of CDM projects and national initiative for GHG reductions

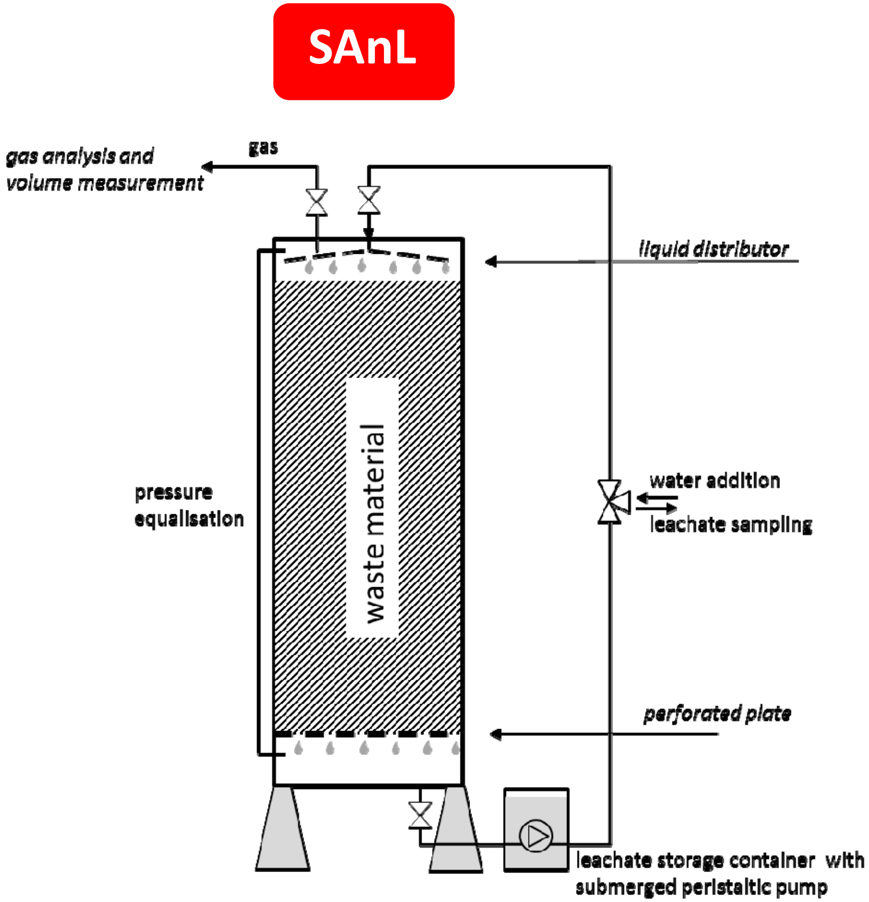
- **Preparation for landfill mining**
  - Reduction in methane concentration (labour safety) and avoidance of odours

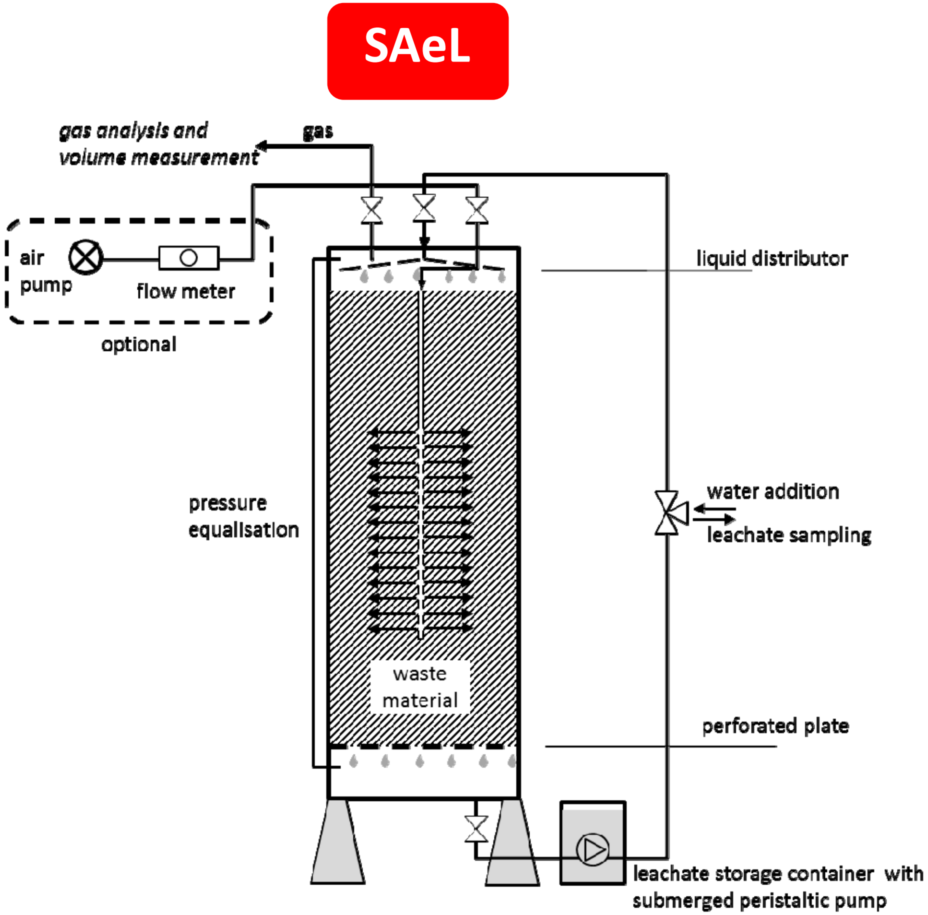
- **Prevention of hazards**
  - Avoidance of LFG migration and reduction of LFG formation

Results from simulated landfills

(anaerobic and aerobic)

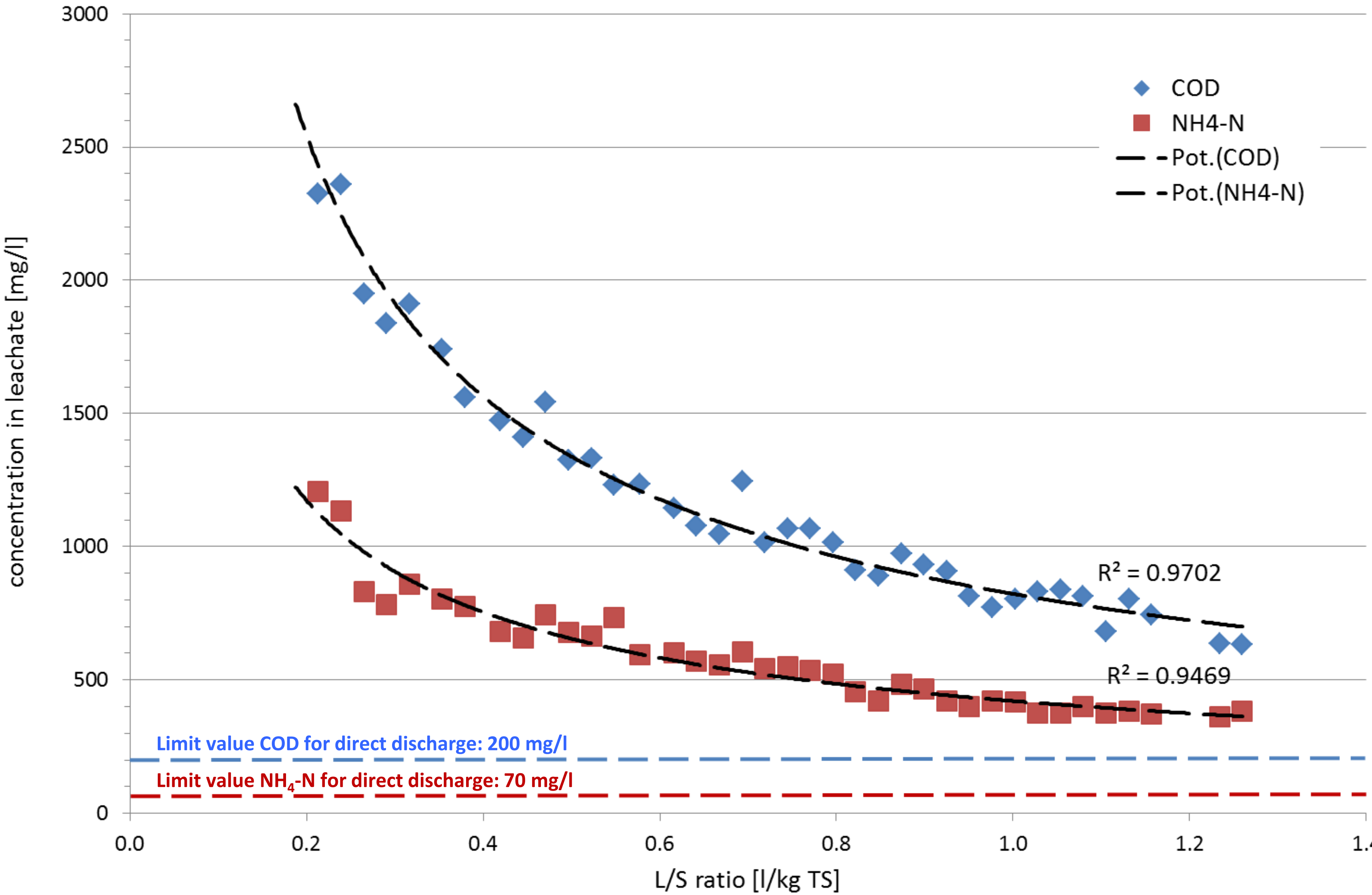
Simulated anaerobic and aerobic landfills





Operation at mesophilic temperature (36°C)

SAnL: Evolution of COD and NH_4-N



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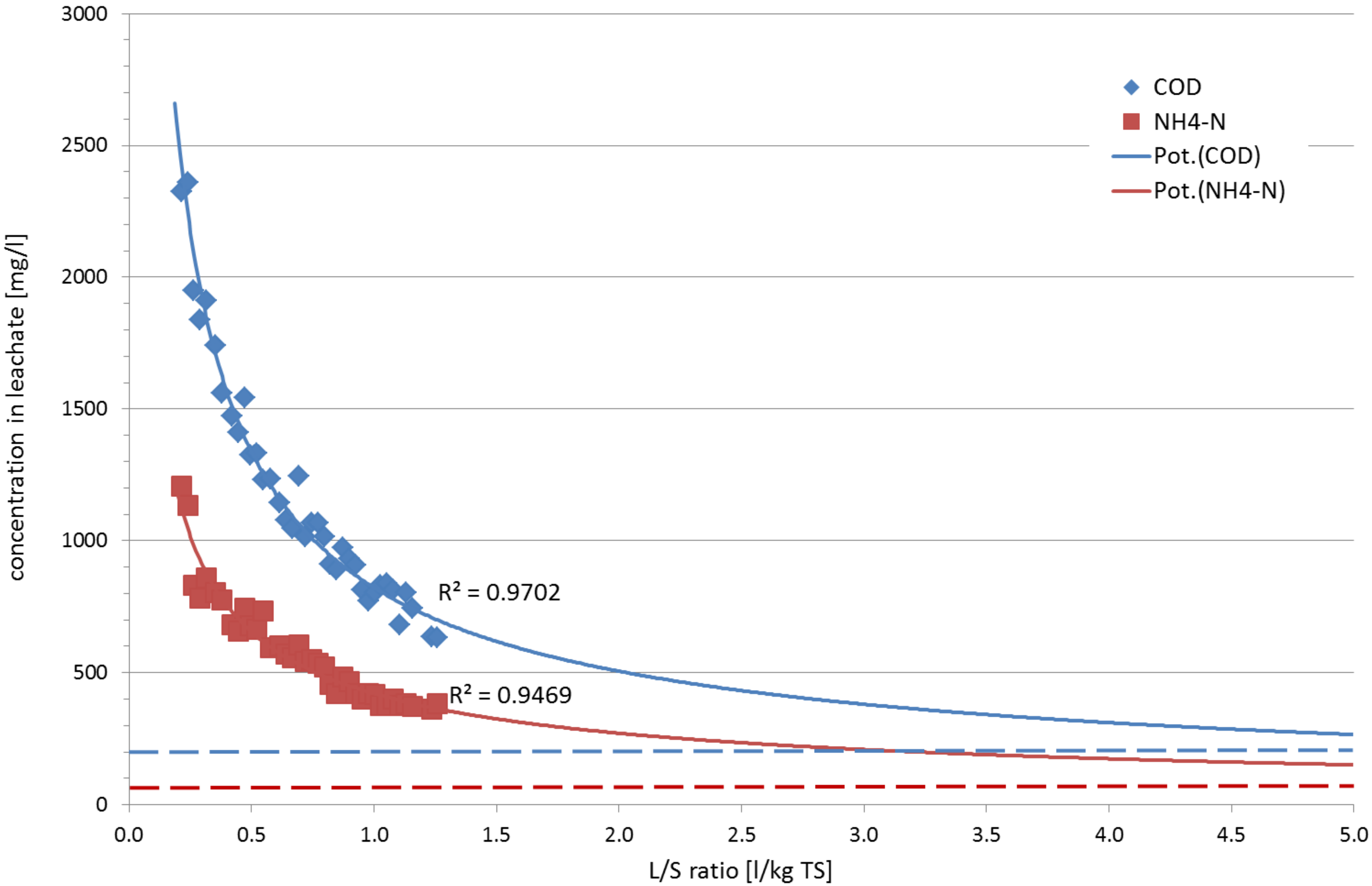
SAnL: Evolution of COD and NH_4-N



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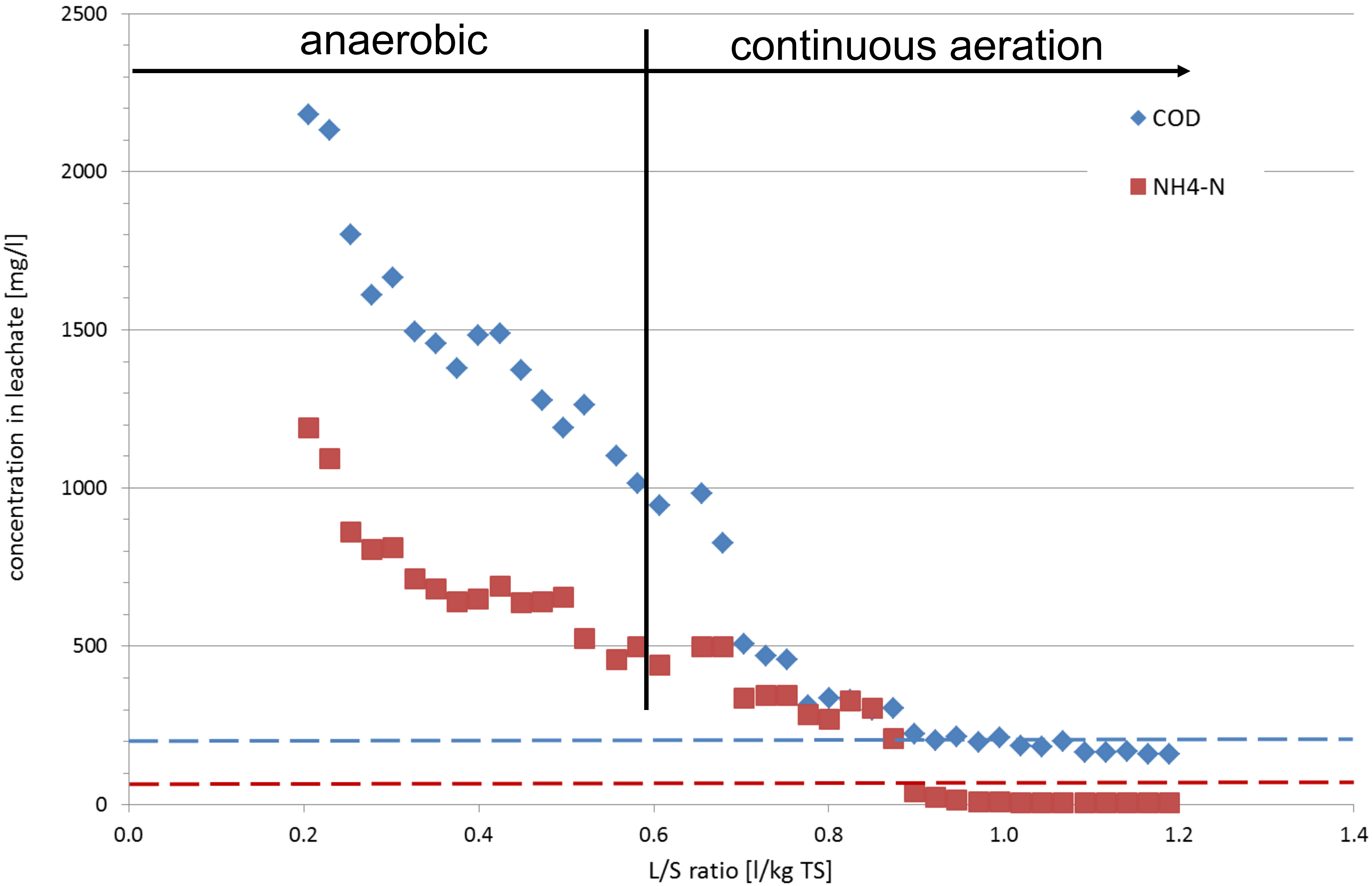
SAeL: Evolution of COD and NH_4-N



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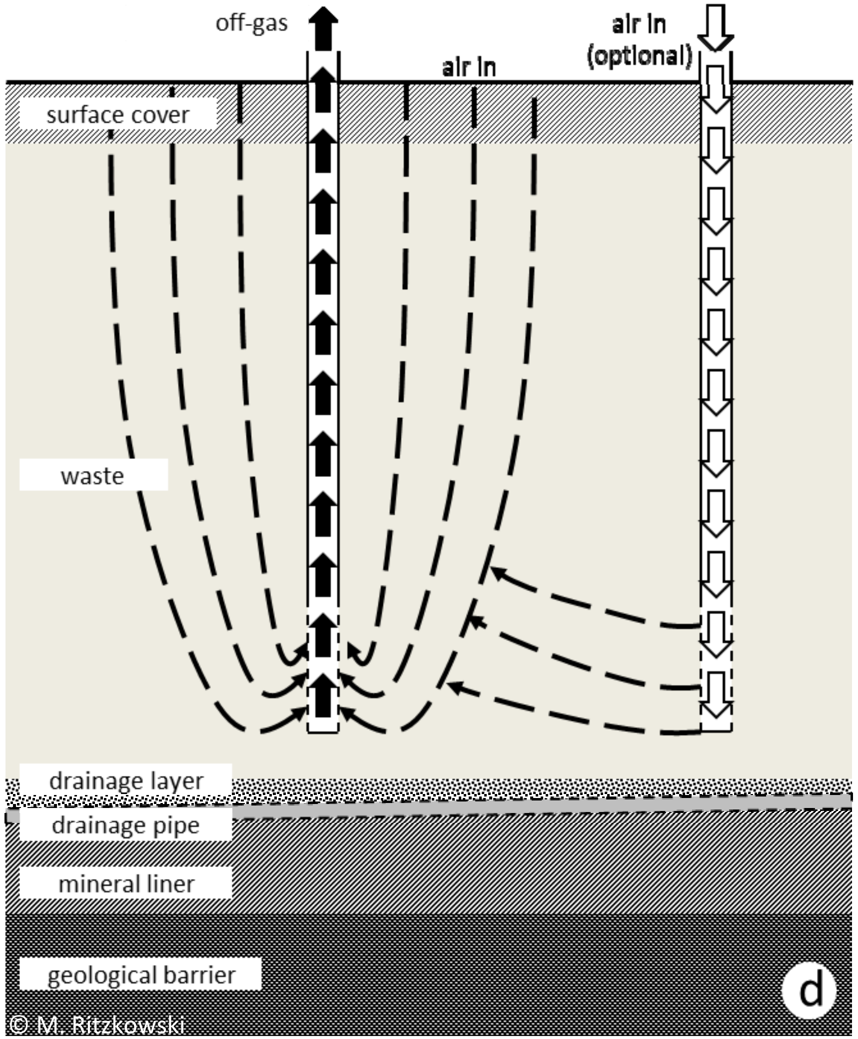
Converting lab scale to full scale: conceptual approaches

Low pressure aeration (LPA)

- passive aeration (air venting) -



Specifications:

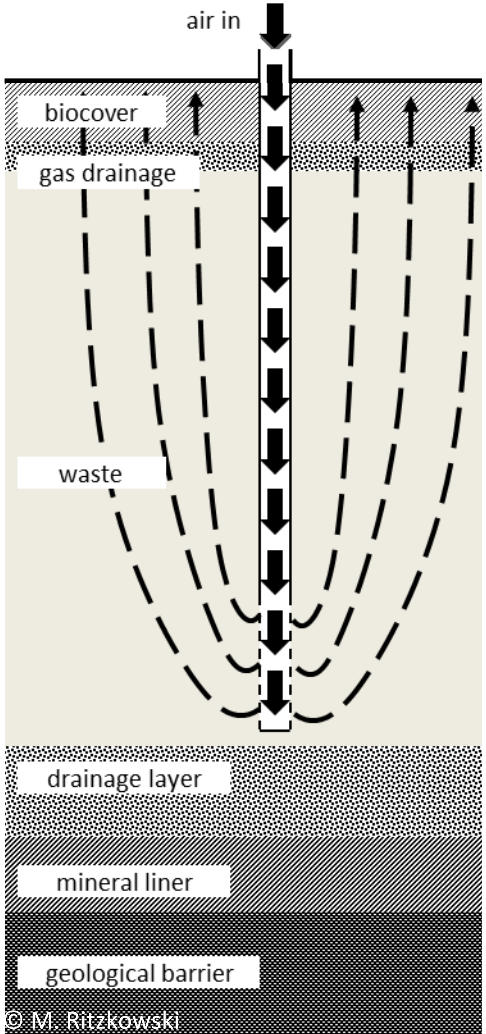
- Aeration driven by **negative pressures** induced inside the landfill;
- Gas wells are **perforated** only in the **lower part;**
- **Gradual aeration form the surface to deeper waste layers**
- Off-gas treatment by means of **biofilters or RTO**
- **Two stage performance:**

1. **Increased methane flux as a result of increased flow rates**
2. **Gradual aeration effect**

***e.g. DEPO+®*, TUHH-concept**

Low pressure aeration (LPA)

- active aeration w/o off-gas extraction -



Specifications:

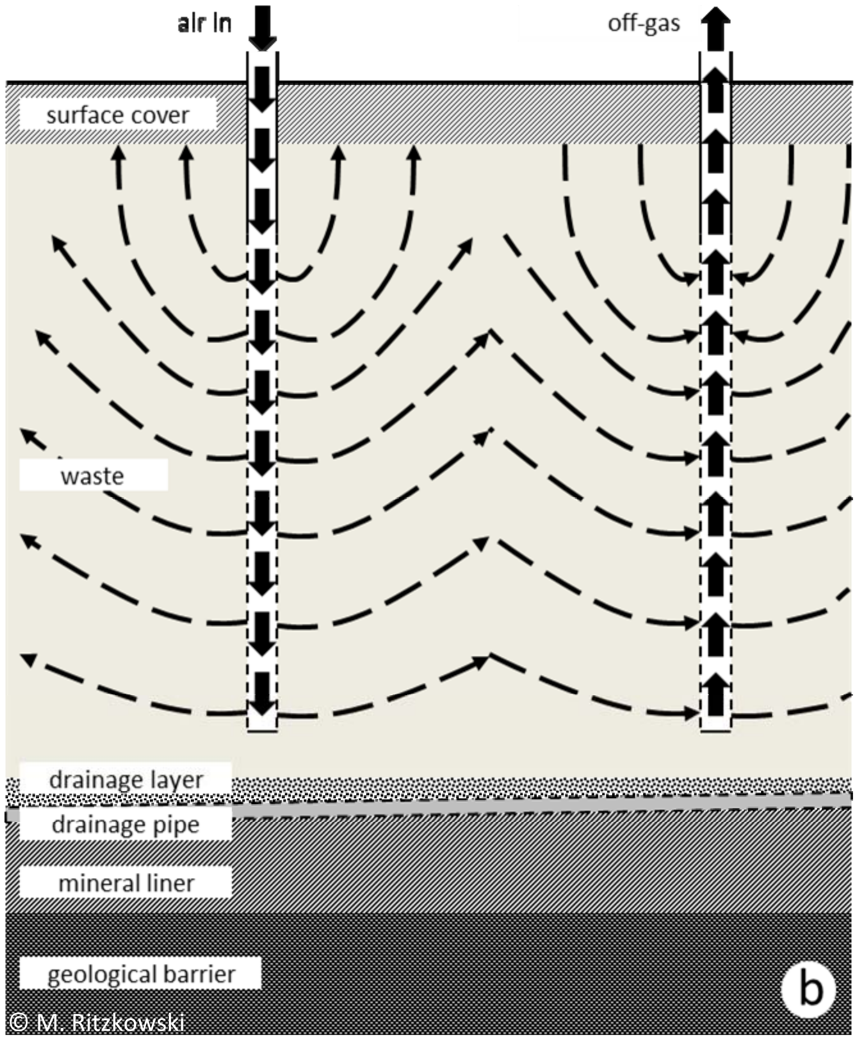
- **Continous aeration** at low pressures (20 to 80 mbars)
- **Air distribution** by means of convection and diffusion
- **Oxidation** of residual methane in the **biocover**

Variation:

- **Air supply into the drainage layer (enhancement of gas distribution)**

Low pressure aeration (LPA)

- active aeration & off-gas extraction -

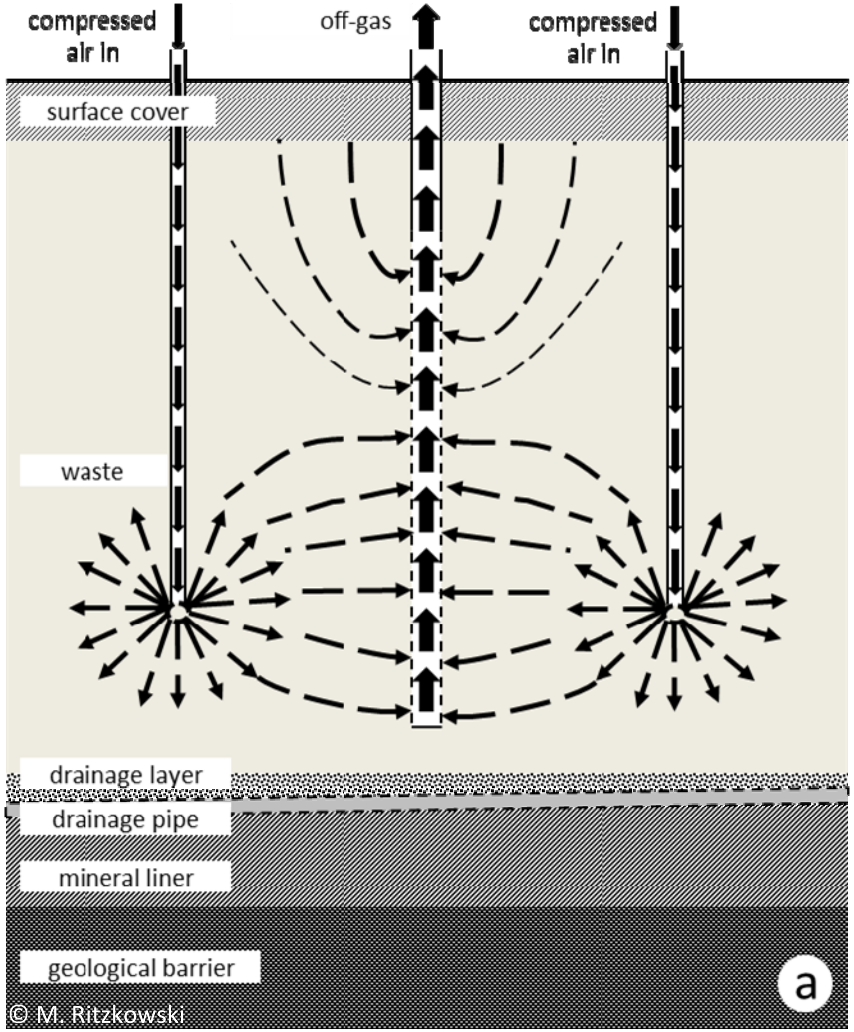


e.g. AERO*flott*®, AIRFLOW®, Smell-Well®

Specifications:

- **Continous aeration** at low pressures (20 to 80 mbars)
- **Air distribution** by means of convection and diffusion
- Parallel **extraction of the off-gases**
- Off-gas treatment by means of **biofilters (+ bio scrubbers) or regenerative thermal oxidation (RTO)**

High pressure aeration (HPA)



e.g. BioPuster®

Specifications:

- **Shock pressure technology (up to 6 bar); blast effect**
- **Ambient air, eventually enriched by oxygen (up to 20%)**
- **Intermittend operation**
- **Off-gas extraction and treatment (filter)**
- **Mainly applied for landfill mining projects**

Examples of full scale aeration projects

Kuhstedt landfill – the first pilot project

- Germany -

Operation	**Middle of the 60's until 1987: Landfill operation** **Waste deposition into a former gravel pit**

Deposited kinds of waste:	**Municipal solid waste, bulky waste, commercial waste similar to household waste, C&D-waste**
Total LF area:	**approx. 3,2 ha**
Landfill height:	**average 7 m (max.: 11m)**
Landfill volume:	**approx. 220.000 m³**
Base liner:	**none**
LFG extraction:	**not applied**
Surface cover:	**soil and sand (20 -100 cm)**

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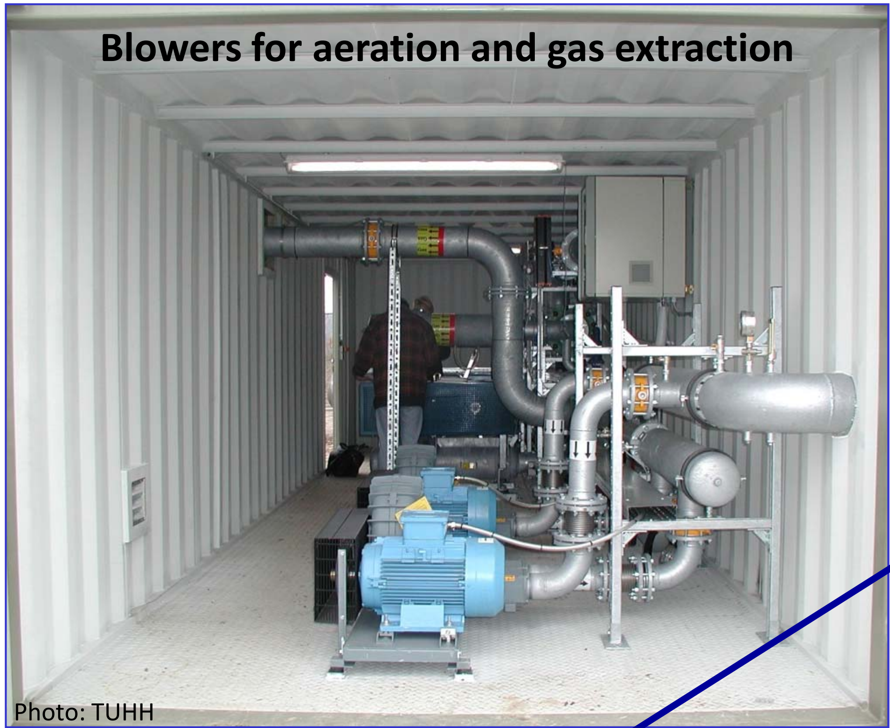
Kuhstedt landfill – the first pilot project

- Technical infrastructure -



Blowers for aeration and gas extraction

Photo: TUHH

Photo: TUHH

Photo: TUHH

Gas distribution garage and valves for regulation of aeration / extraction

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Kuhstedt landfill – the first pilot project

- Technical infrastructure -

Perforated PE-pipe (conventional gas well)

Installation of the clay cap

Kuhstedt landfill – the first pilot project

- Project data -

- Overall duration: 8.5 years
- Start: 1999; Completion: End of 2007
- Aeration period (net): Approx. 5.5 years
- Method applied: AERO*flott*®
  - Low pressure aeration (continuous operation)
  - Parallel aeration / off-gas extraction
  - Off-gas treatment by means of regenerative thermal oxidation (RTO) and bio-scrubber / bio-filter combination (in the later stage of stabilization)


Photo: TUHH


Photo: TUHH


Photo: TUHH

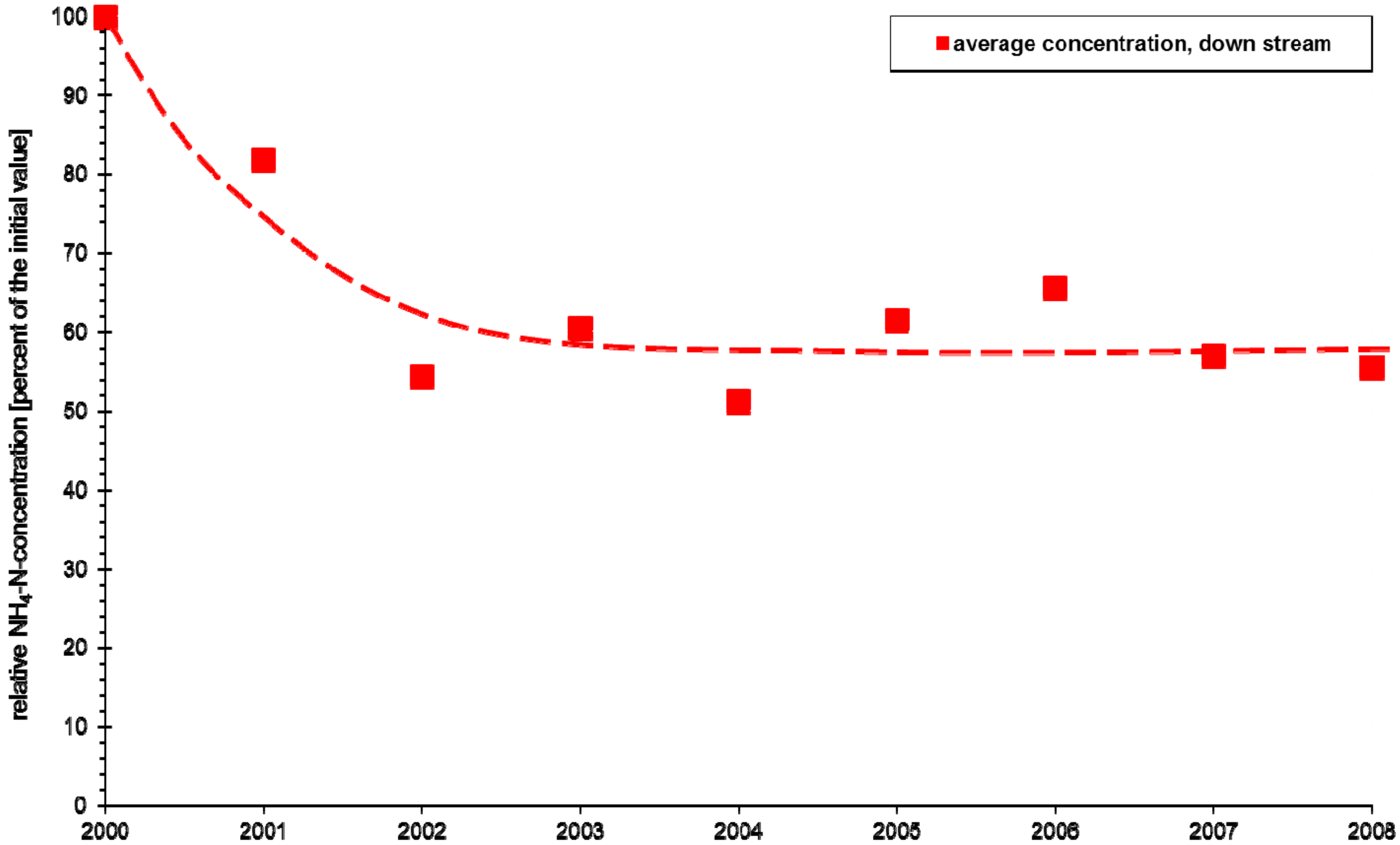
Kuhstedt landfill – the first pilot project

- Project results -

- **Carbon conversion rate**: > 90% (of biodegradable TOC);
- **Carbon discharge** 5 - 7 times faster in comparison with anaerobic landfill;
- Small residual **LFG potential** after completion of aeration: < 2 m^3/Mg TS (based on LSR tests);
- **Methane production rate**: < 0.3 l CH_4/m^2*h (based on gas extraction test in 08/2006);
- Improved **groundwater** quality

Kuhstedt landfill – the first pilot project

- Development of NH_4-N in groundwater -



Kuhstedt landfill – the first pilot project

- 2015 – after recultivation -

Dörentrup landfill – the first TASi II project

- Germany -

Operation period	**1985 until 1999** **Waste deposition into a former sand pit**

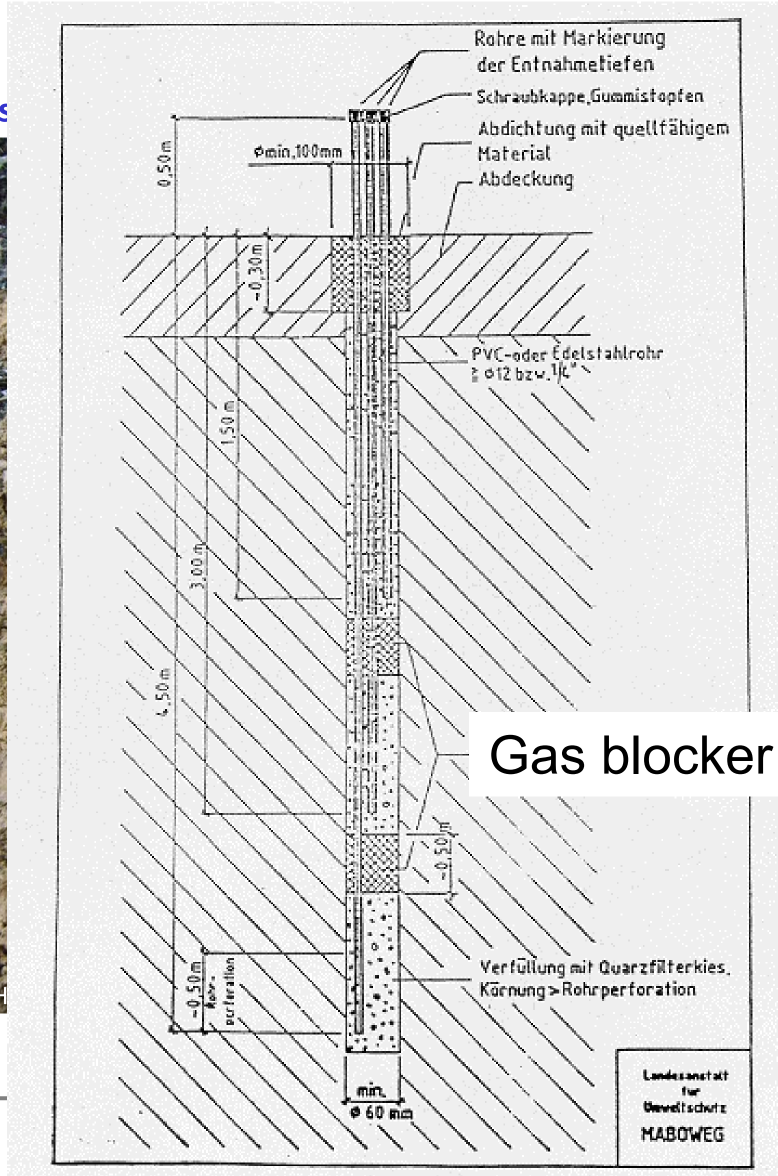
Deposited kinds of waste:	**Municipal solid waste, bulky waste, commercial waste similar to household waste, sludge (WWT)**
Total LF area:	**approx. 8.6 ha**
Landfill height:	**average 25 m**
Landfill volume:	**approx. 1.100.000 m³**
Base liner:	**yes, with leachate collection**
LFG extraction:	**not applied**
Surface cover:	**soil**

Data and photo: IFAS (Hamburg)

Dörentrup landfill – the first TASi II project

- Technical infrastructure -

Gas wells



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Dörentrup landfill – the first TASi II project

- Technical infrastructure -

Mains Pipes and Gas Booster Station


Photo: IFAS (Hamburg)

Blowers for air injection

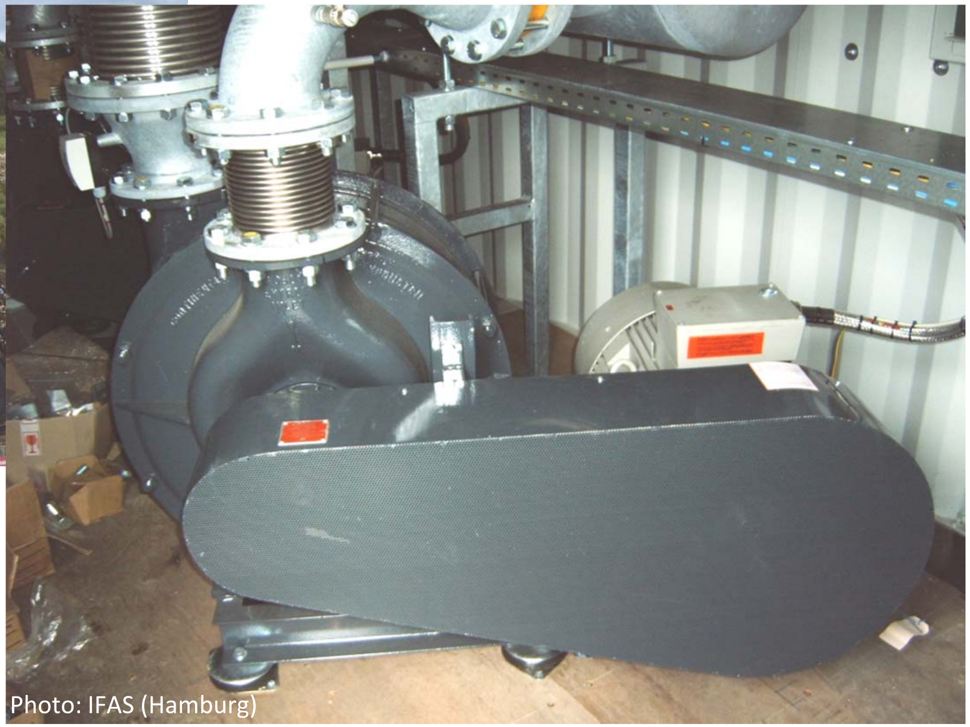
Photo: IFAS (Hamburg)

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Dörentrup landfill – the first TASi II project

- Project data -

- Overall duration: 8 years +
- Start: 2008; aeration ongoing
- Aeration period (net): Approx. 7 years +
- Method applied: AERO*flott*®
  - Low pressure aeration (continuous operation)
  - Parallel aeration / gas extraction
  - Off-gas treatment by means of regenerative thermal oxidation (RTO)

Avoided GHG emissions: approx. 50,000 Mg $CO_{2,e}$

Photo: IFAS (Hamburg)

Dörentrup landfill – the first TASi II project

- 2012 – after installation of a PV plant -

Teuftal landfill – pilot project in Switzerland

Operation (Bioreactor LF)	**1973 until 2000** **Waste deposition into a valley ; re-allocation of a stream** (side slopes of the valley with constant water head)
Deposited kinds of waste:	**Municipal solid waste, bottom ash, excavated soil, sludge** ***Waste emplacement in thin layers, high compaction***
Total area:	**approx. 12 ha**
Landfill height:	**up to 35 m of "reactive" waste; overlain by > 10m of soil**
Landfill mass:	**approx. 2.1 M tons TS**
Base liner:	**yes, with leachate collection**
LFG extraction:	**yes, horizontal drainage systems for combined LFG and leachate collection**
Surface cover:	**Liner (slope area) and soil (plateau)**

Data and photo: TUHH and Deponie Teuftal AG

Teuftal landfill – pilot project in Switzerland

- Aeration concept -

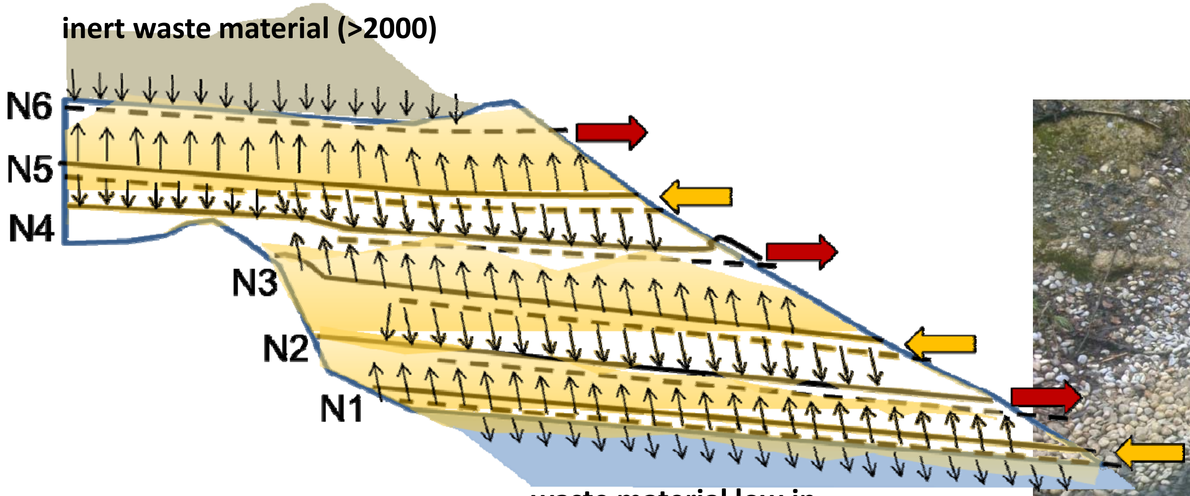



Photo: TUHH

- **Scheduled air flow rate:**

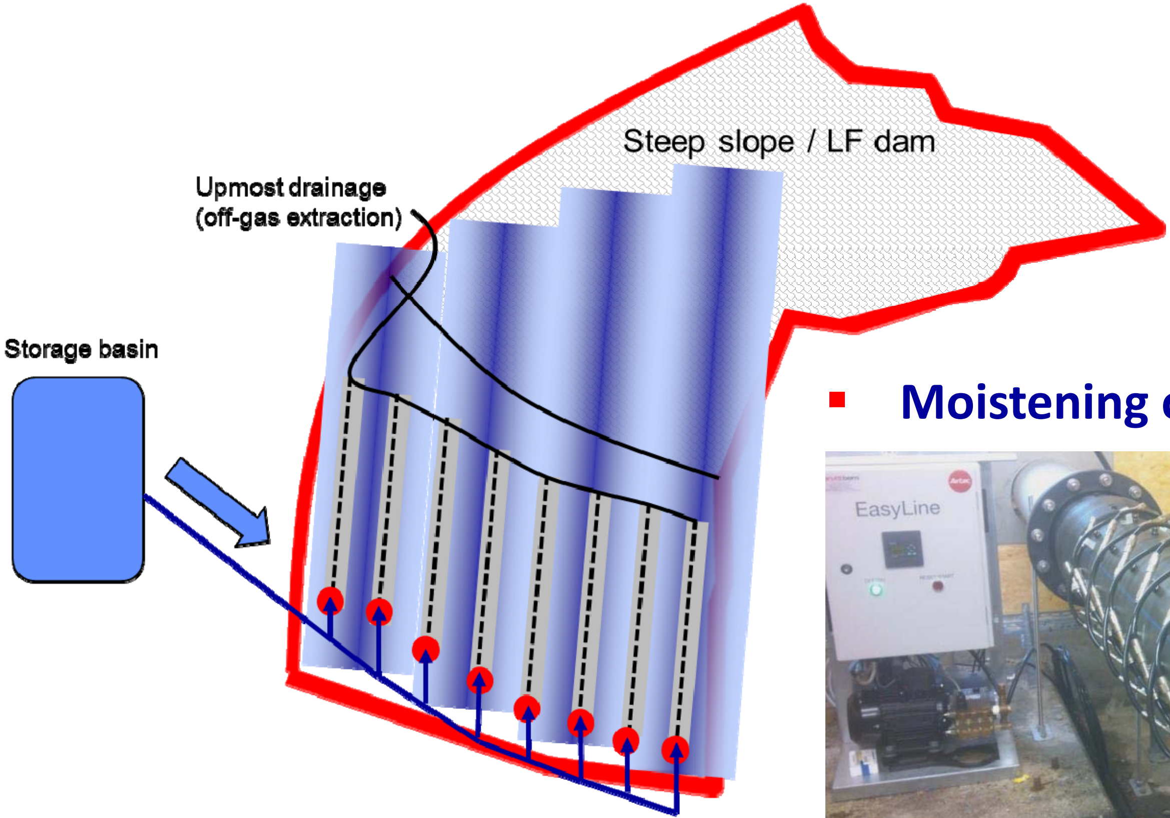
  1.000 – 2.000 m³/h (at 150 – 250 mbar positive pressure; based on pre-tests)

- **Energy efficient screw blowers with high capacity**

Photo: TUHH

Teuftal landfill – pilot project in Switzerland
- Waste irrigation concept -

- **Utilisation of the existing drainage networks**



- **Moistening of the injected air**

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Teuftal landfill – pilot project in Switzerland
- Preliminary results -

- **approx. 14.8 M m³ air injected (01/2015-10/2016)**
  (≈ 7 m³ per Mg TS)
- **1,137 Mg C discharged**
  (≈ 0.54 kg C/Mg TS)
- **Plant availability (01-10/2016): 96%**
- **Temperatures (waste): 25 – 46 °C (increase by 4°C on average)**

Ongoing projects

- Examples -

in situ aeration of the Bornum landfill, Germany

- **Since 08/2014**
- **Saving of up to 84,000 tons $CO_{2,e}$**

Data: IFAS (Hamburg)

Examples of landfill aeration in Europe

- Germany -

- **Amberg-Neumuehle landfill (completed)**
- **Milmersdorf landfill (completed)**
- **Schwalbach-Griesborn landfill**
- **Suepplingen landfill**
- **Bornum landfill (since 2013)**
- **Dibbersen landfill (since 2013)**
- **Hellsiek landfill (since 2014)**
- **Goldlauter landfill (since 2015)**
- **Helvesiek landfill (since 2015)**
- **Coesfeld-Höven (since 2015)**
- **+ several more**

Photos: IFAS (Hamburg)

Examples of landfill aeration in Europe

- Germany -

passive aeration – oversuction:

- **Kiel Drachensee landfill**
- **Schenefeld landfill**
- **Barsbuettel landfill**
- **Stemwarde landfill (I), (II)**
- **Oher Tannen landfill**
- *Landfills Baldurstr-Bockholtstr./Kassenberger Str. (Bochum)*
- *Landfill Dorstener Straße (Oberhausen)*
- *A couple of further projects since the middle of the 80ies*

(Kiel Drachensee, Schenefeld and Barsbuettel landfills:) **Intensive afteruse**
(buildings, residential & commercial areas)


Barsbüttel landfill


Kiel Drachensee landfill


Kiel Drachensee landfill

Examples of landfill aeration in Europe

- Germany -

active aeration w/o off-gas extraction:

- **Konstanz-Dorfweiher landfill**


Konstanz-Dorfweiher landfill


Konstanz-Dorfweiher landfill


Konstanz-Dorfweiher landfill

Photos: Roth GmbH

Examples of landfill aeration in Europe

- Austria -


Mannersdorf landfill

active aeration & off-gas extraction:

- **Mannersdorf landfill**
- **Heferlbach landfill**

active aeration w/o off-gas extraction

- **Bale landfill Pill**


Picture: H. Passer
Pill landfill


Heferlbach landfill

Examples of landfill aeration in Europe

- Switzerland -

passive aeration – oversuction:

- **Sass Grant landfill (Engadin)**

active aeration & off-gas extraction:

- **Teuftal landfill (Bern)**

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Examples of landfill aeration in Europe

- The Netherlands -

passive aeration - oversuction:

- **Braambergen landfill**

active aeration:

- **Landgraaf landfill**

Examples of landfill aeration in Europe

- Italy -

active aeration & off-gas extraction:

- **Modena landfill**
- **Legnago landfill**
- **Campodarsego landfill**
- **...**

Photo: IMAGE, Padova

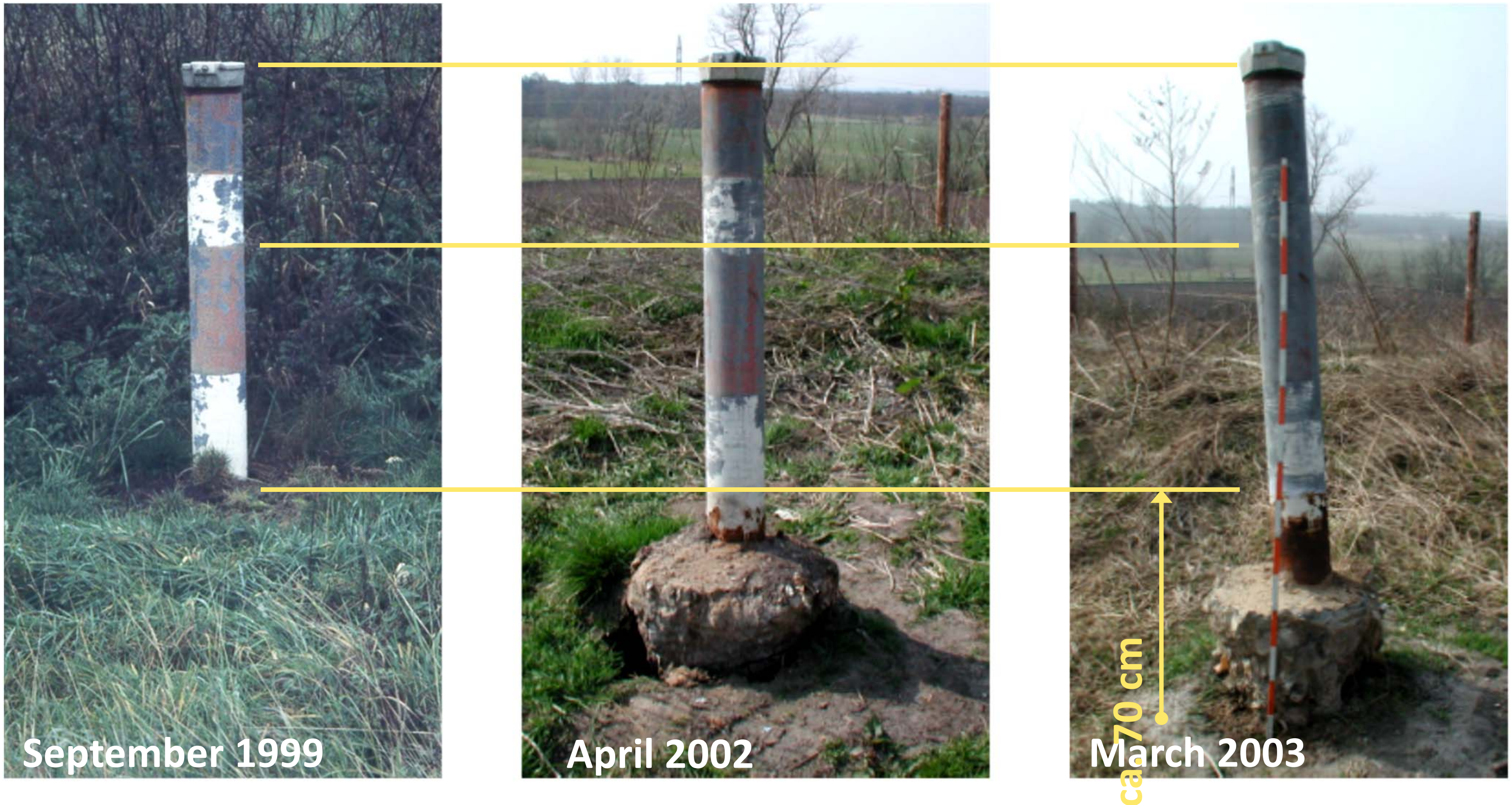
Photo: IMAGE, Padova

Photo: IMAGE, Padova

Full scale aeration projects

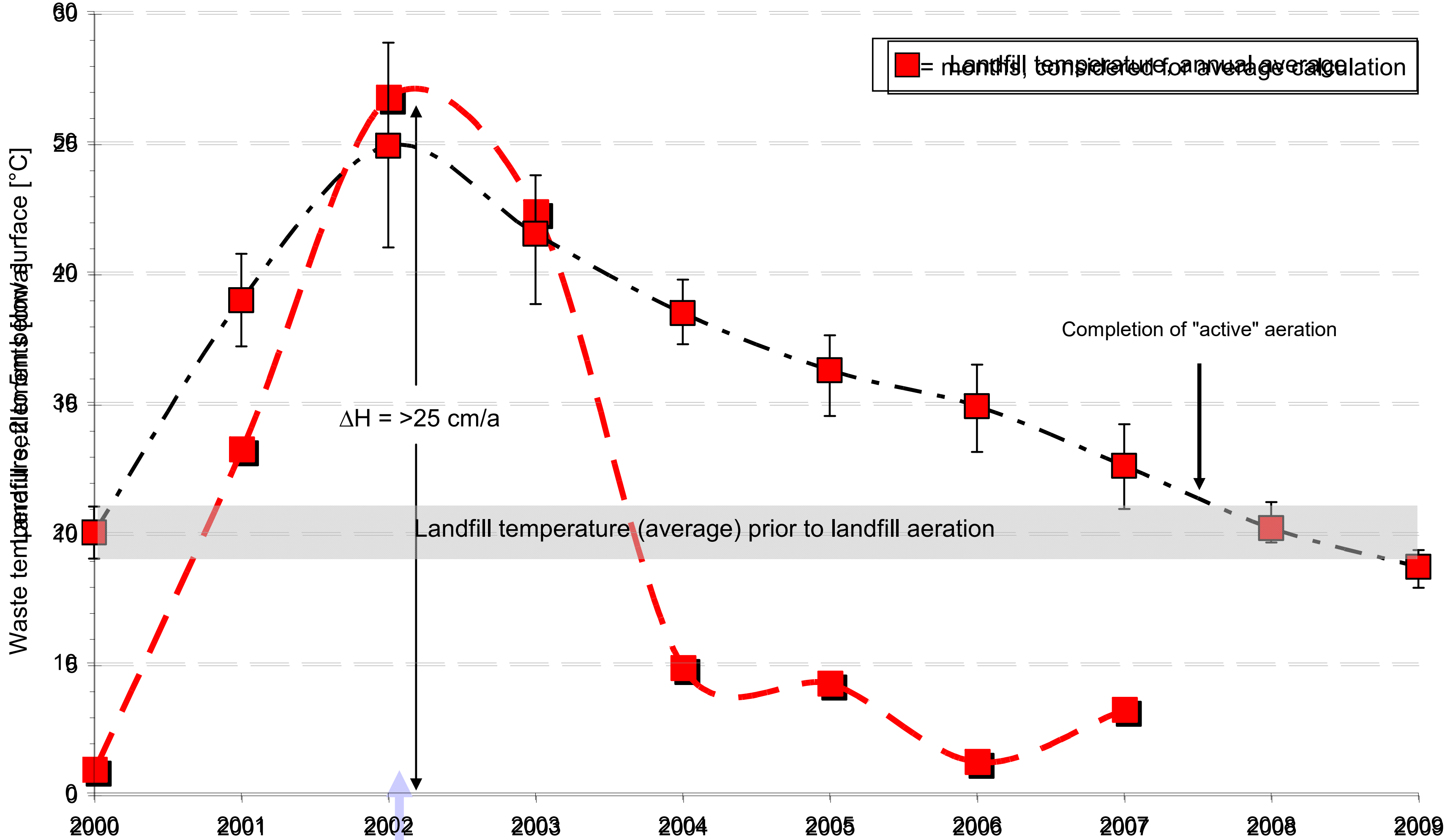
- Results -

Intensified settlements



Photos & data: TUHH

Intensified settlements & increasing waste temperatures



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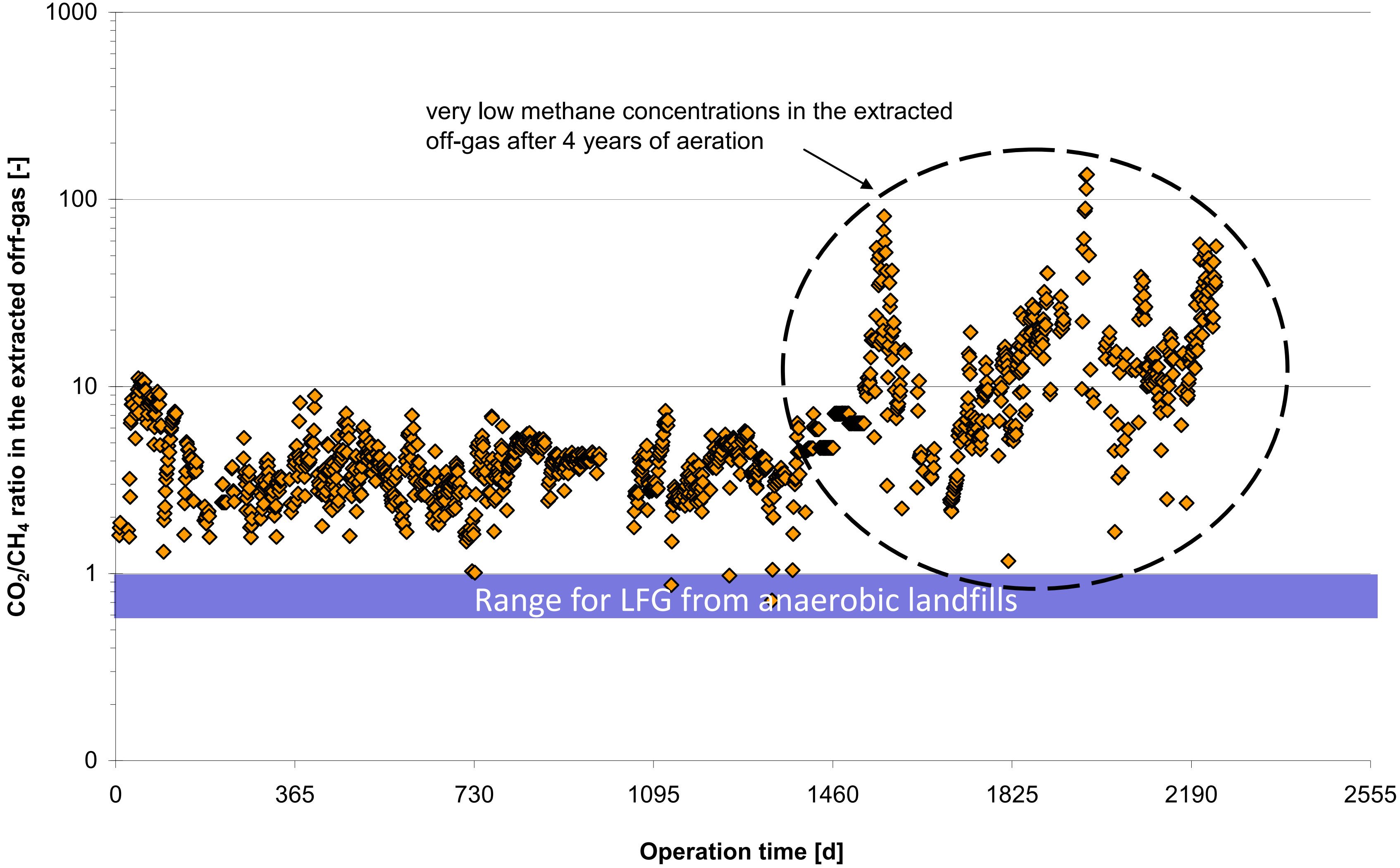
Performance (I): Methane production



Data: Kuhstedt landfill (M. Ritzkowski)

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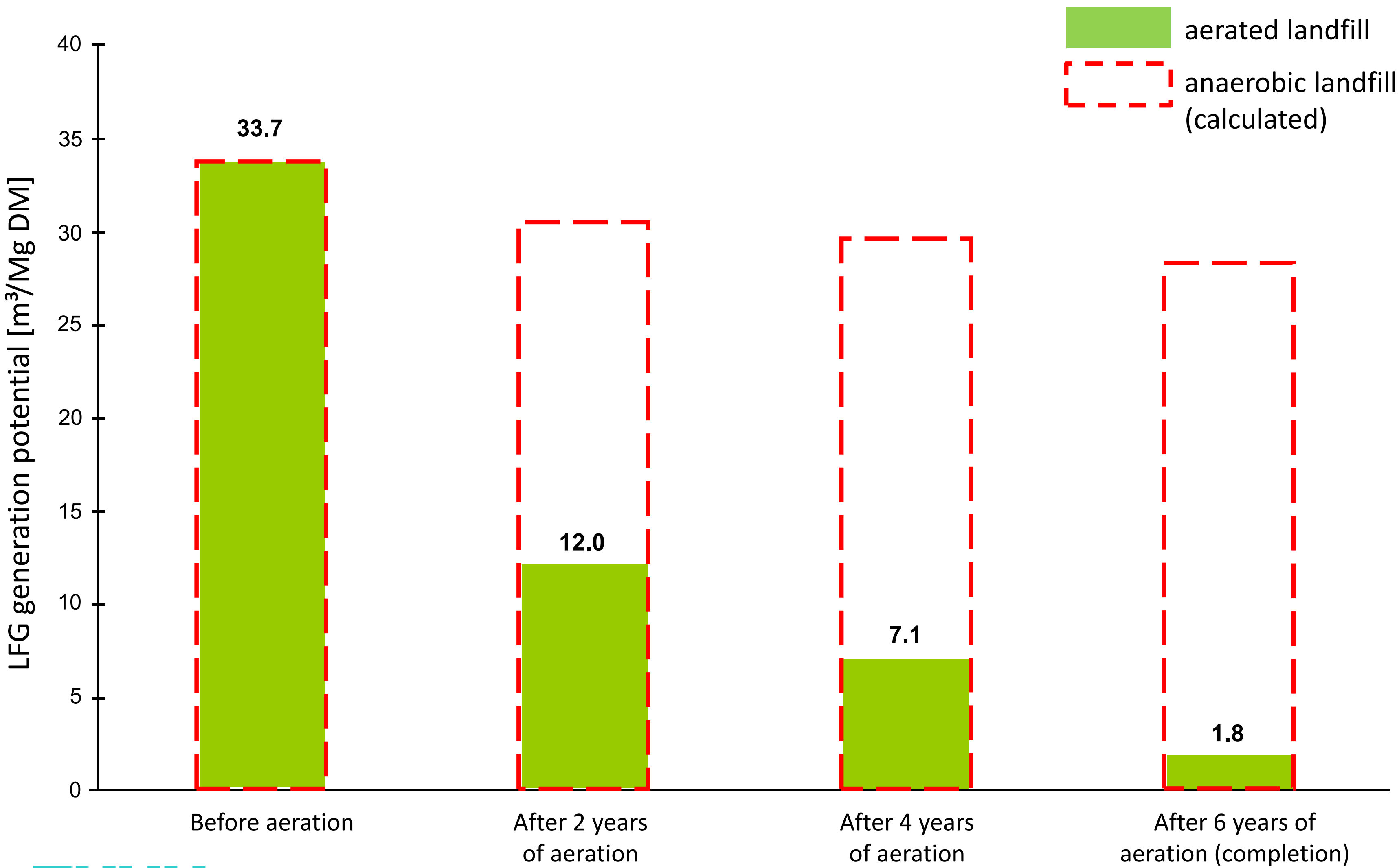
Performance (II): LFG potential



Data: Kuhstedt landfill (M. Ritzkowski)

Solid waste samples before and after aeration

Waste sample before aeration

Waste sample after aeration

Leaching tests* of aerated waste material

parameter	unit	before aeration	after 2 years	after completion	LF class I	LF class II	MBP LF
BOD_5	mg/l	190	28	15.4	--	--	--
TOC	mg/l	235	109	18.4	< 20	< 100	< 300
NH_4-N	mg/l	21	39	5.2	< 4	< 200	< 200
AOX	mg/l	0.683	0.33	0.028	< 0.3	< 1.5	< 1.5
Electrical conductivity	mS/cm	1.2	1.1	0.4	< 10	< 50	< 50

Reduction of discharged pollutants: > 80% (TOC); > 90% (NH_4-N)**

* Leaching test according to DIN 38414, DEV S4 (L/S-ratio = 10)

** Results of long-term lysimeter tests (L/S-ratio = 4.5)

Lab scale vs full scale

(do we simulate the reality?)

Carbon flux

Findings:

- Higher aeration rates during lab scale tests (often 10:1);
- Good air distribution, less channeling (compared to full scale);
- Very high oxygen conversion rates in lab scale (80 – 90%), in full scale the range is significantly lower (20 – 50%);
- Waste moisture content shows no influence on carbon flux.

Consequences:

- Longer aeration periods in full scale;
- If the oxygen conversion rate in full scale has been identified, the required aeration period can be determined.

Leachate quality

- Landfill **aeration impacts on leachate** quality, but
- Simulation tests in lab scale often **do not adequately consider** the conditions to arise during full scale projects;
- One of the major factors to determine the leachate composition during aeration is **temperature**:
  - Raising temperatures stimulate / intensify both, nitrogen mineralization rates (ammonification) as well as bioconversion of organic compounds, nitrification is inhibited;
  - Consequently the pH value is increasing and becomes the major driver for further processes;
  - Due to a shift in the ammonium – ammonia equilibrium (towards free ammonia) nitrification processes are further inhibited and the same applies for microbial bioconversion processes of organic compounds.

Leachate quality (II)

- With the beginning of NH_3-N volatilization both, organic and nitrogen compounds in the leachate are reduced and with the transition into the long term cooling phase (at reduced microbiological activity) the positive impact of aeration on the leachate composition (quality) becomes apparent.

- The potential long term release of ammonium nitrogen (incorporated in the microbial biomass) once the aeration has been completed seems to be circumstantial.

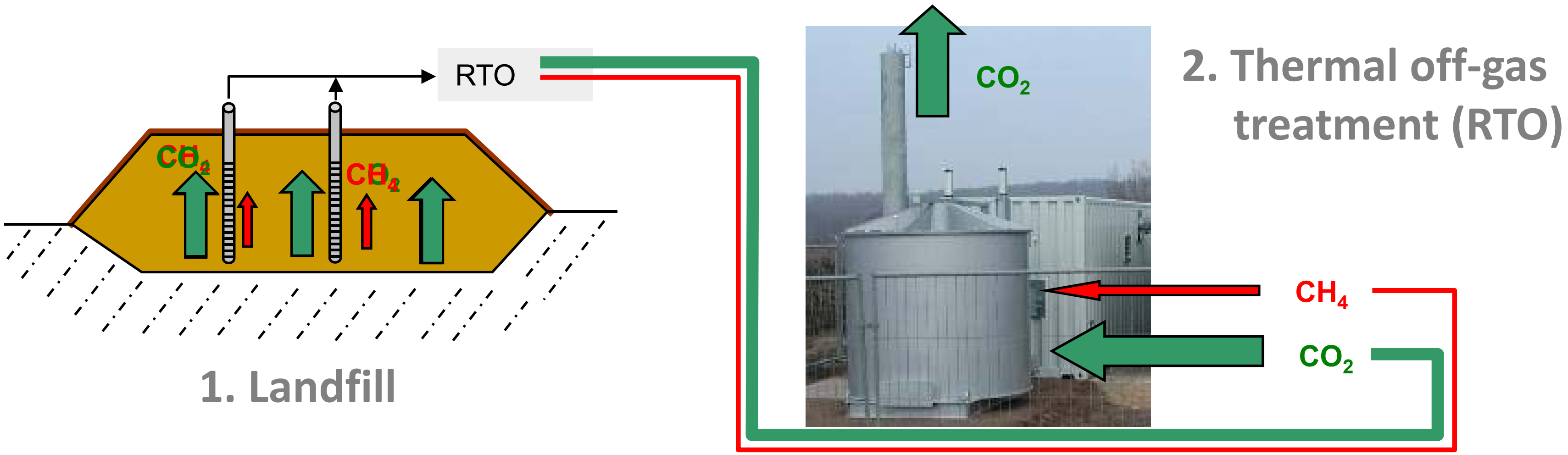
- Investigations in laboratory scale indicate that the nitrogen mineralization rates (ammonification) after a widely bio-stabilization are in a range of <30% in comparison with the situation at the start of aeration.

The temperature evolution during landfill aeration has to be considered during the lab scale tests.

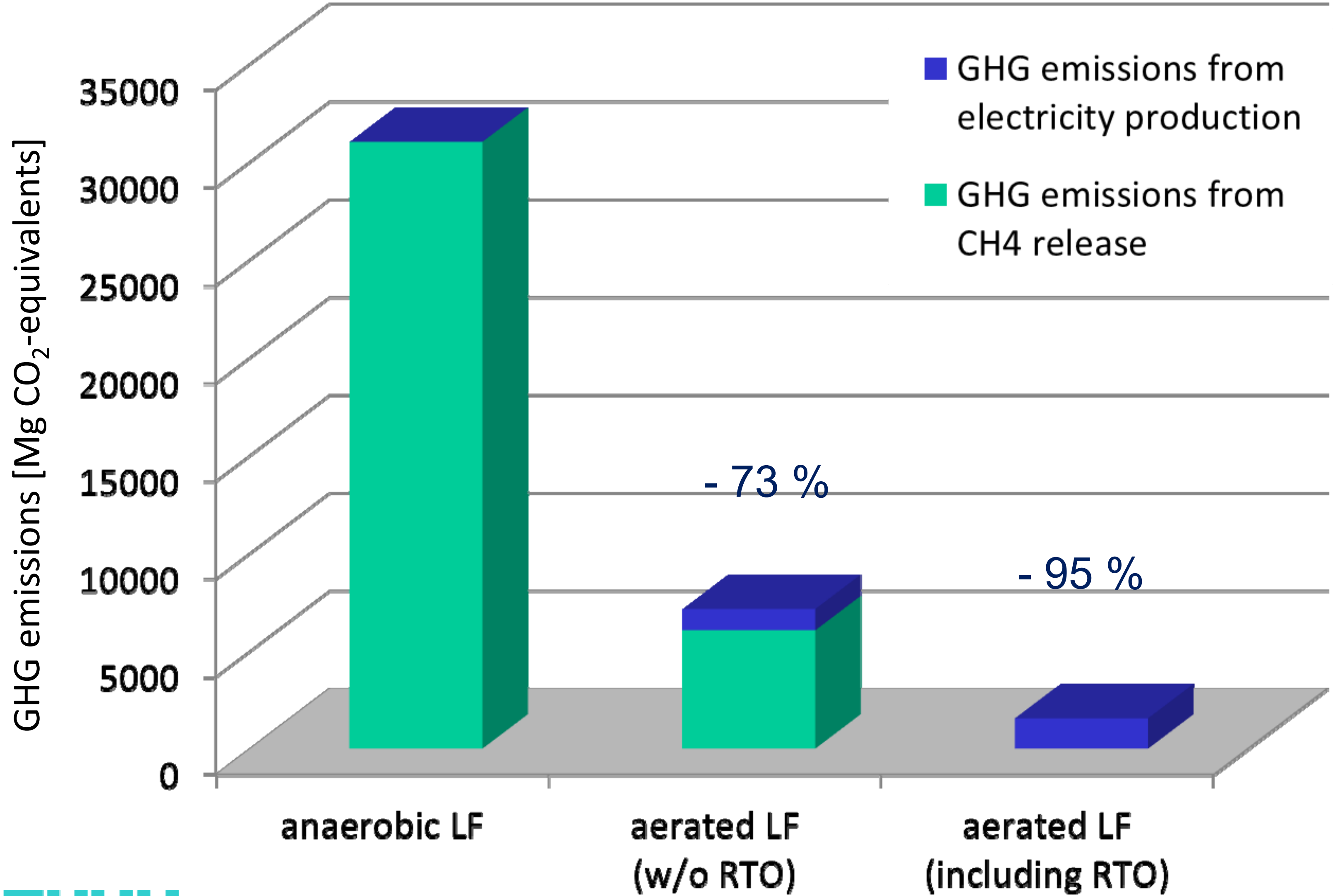
The importance of off-gas treatment

Reduction of diffuse GHG emissions

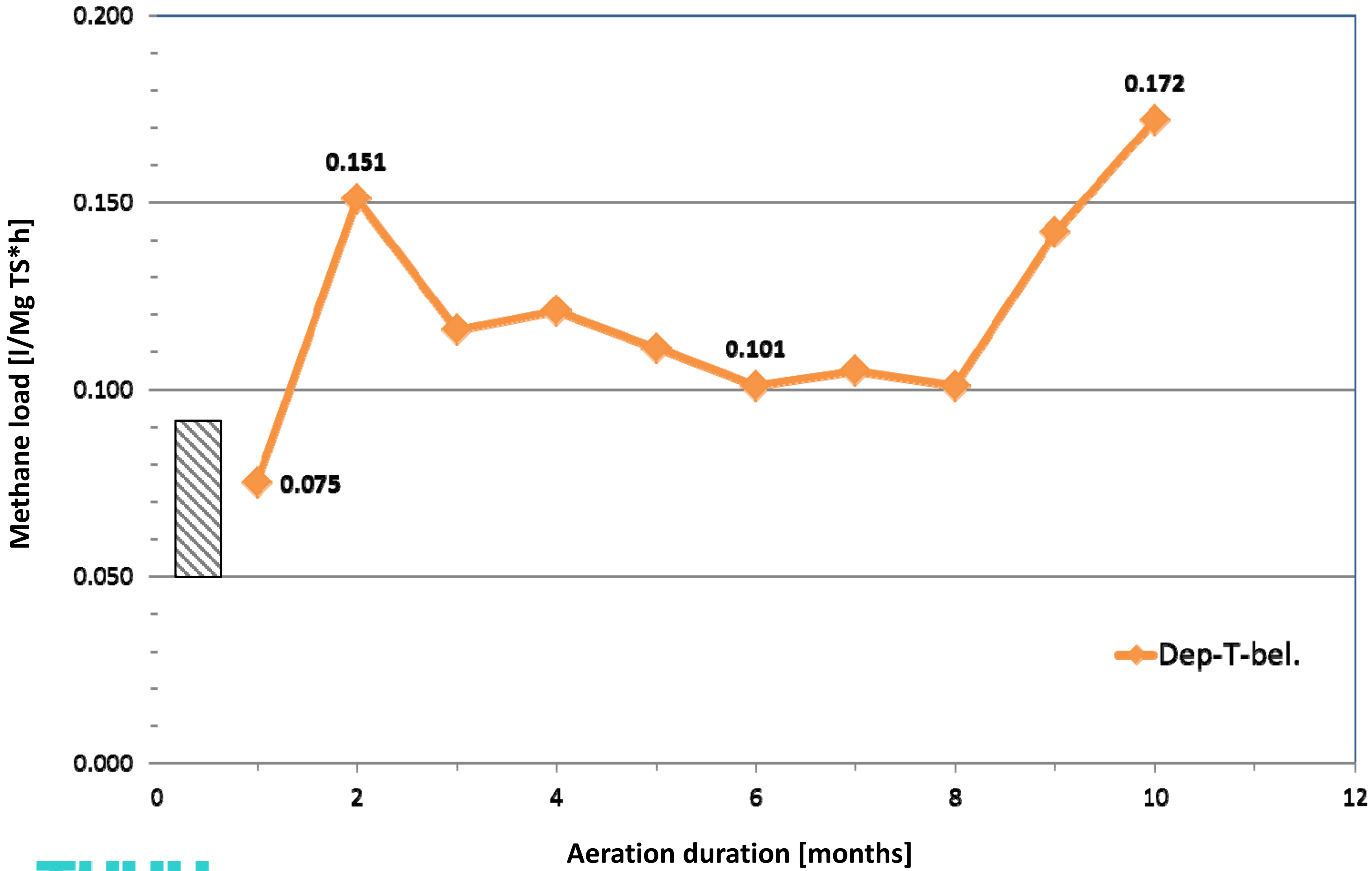
- **The generation and release of methane (major contributor of GHG emissions from landfills) can be widely avoided.**
- **The amount of secondary GHG emissions (energy and fossil fuel consumption, N_2O production) is relatively low.**
- **GHG emission reductions can be achieved in two fields:**



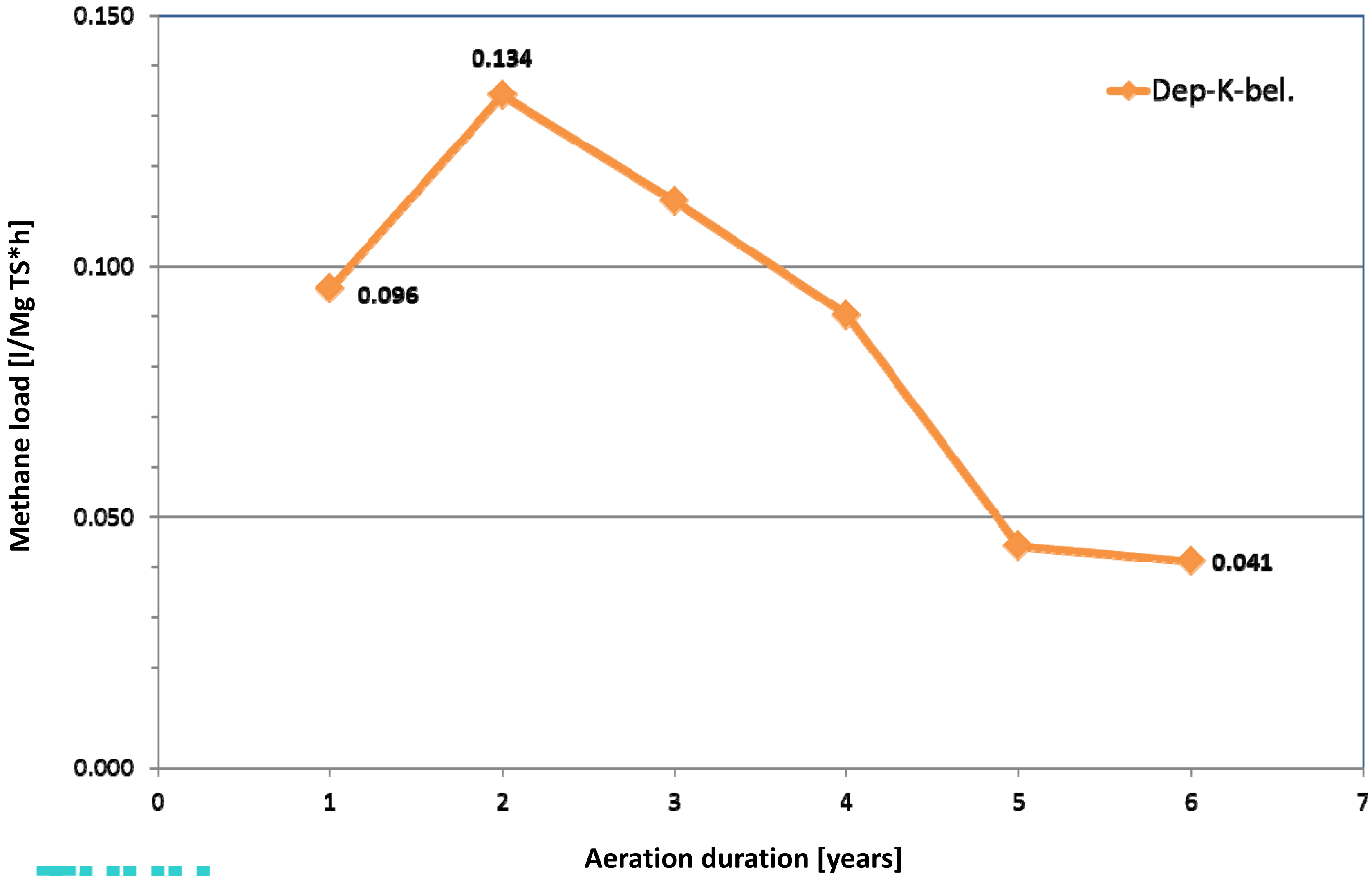
Reduction of diffuse GHG emissions



Methane load in extracted off-gas



Methane load in extracted off-gas



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Criteria for the completion of aeration

On-site criteria

Criteria / Parameter	Definition / Proof	Value/ Dimension
Organic carbon degradation	Determination by means of CO_2 in the off-gas; Value based on monitoring results and calculations	C- Degradation ≥ 90% of the biodegradable $C_{bio.}$
LFG production (based on extraction test)	Measured 4 weeks after LFG extraction has been stopped	CH_4-production ≤ 0,5 l/m²*h (if A>5ha → ≤ 25 m³ CH_4/h)
Settlements	Average over total landfill area	significant reduction
Temperatures	In situ monitoring in different depths and areas	Decreasing to levels before aeration, Difference < 5 – 10°C

Limit values for CH_4 production

A ≤ 5 ha

LF height [m]	Limit value [l CH_4/Mg TS*h]
5	0,150
10	0,077
15	0,051

A ≥ 5 ha (**10 ha**)

LF height [m]	Limit value [l CH_4/Mg TS*h]
10	0,038
20	0,019
30	0,013

assumptions: waste density = 1Mg/m³; TS = 65%

off-site criteria

Additional Criteria: Analysis of Waste Samples from Landfill Body in Laboratory Tests		
LFG production (Lab. Test, GB_{21})	Target value of in-situ aeration for release from aftercare	$GB_{21} \leq 10$ l/kg TS
Respiration Rate (AT_4)	Target value of in-situ aeration for release from aftercare	$AT_4 \leq 2{,}5$ mg O_2/g TS
Eluate Quality	Eluate-target value of in-situ aeration for release from aftercare	Target Value German LF Class I DepV, 2009 + NH_4-N, AOX

Comparison Austria - Germany

	unit	Proposal **Austria**	Proposal **Germany**
Solid Waste Properties			
Respiration index (RI_4)	[mg O_2/g DM]	< 2.0	2.5
Gas formation potential (GP_{21})	[l / kg DM]	< 2.0	10
Eluate parameter (leaching test)			
BOD_5	[mg/l]	< 300	
COD	[mg/l]	< 1,500	
BOD/COD	[-]	< 0.2	
NH_4-N	[mg/l]	< 400	
Leachate			
BOD_5	[mg/l]	< 100	improved quality
COD	[mg/l]	< 500	
BOD/COD	[-]	< 0.2	
NH_4-N	[mg/l]	< 200	
Carbon discharge rate			
C-mobilized	[% C_{mobile}]	80	90
LFG production rate	[l CH_4 / (m^2*h)]	< 1.0	< 0.5
LF temperature	[-]		decreasing tendency
LF settlements	[-]		significant reduction

Costs

Aeration is not for free…

- **Parallel aeration and off-gas extraction and/or treatment:**

  € 0.45 - € 7.0 per ton waste material to be aerated

  (investment an operation costs for 8 years; European projects)

- **Aerated landfills in the US (aerated bioreactor):**

  $ 3.0 – 5.0 per ton of waste material to be aerated

  (including infrastructure and monitoring and operation)

The cost ranges are mainly associated with **specific local conditions**: **small landfills** without existing infrastructure (e.g. gas wells, blowers, etc.) exhibit **higher investment** costs in comparison to **larger landfills** (which have been formerly operated anaerobically) with **existing gas extraction systems**.

…but there are savings in the medium & long term

- **No need for lean gas treatment** (during the aeration period and thereafter)**;**
- **Final top cover with one sealing element (either geomembrane or clay) instead of double liner** (according the German landfill ordinance, for landfills which have been bio-stabilized by means of aeration)
- **Reduced costs for leachate treatment** (target values will be observed earlier);
- **Subsidies for investment** (provided by the German Federal Ministry for the Environment) **if the project contributes to GHG emission savings;**
- **Switzerland: KLiCK – LFG technology for the compensation of CO_2 emissions** (financial support by a Swiss donation; e.g. for over suction projects or the integration of thermal off-gas treatment (RTO))

Conclusions

Conclusions (I)

- **Emissions** from anaerobic landfills are **long term problems;**
- It is **unlikely** that regular sized MSW landfills will be **released from post-closure care** (= reach the state of sustainability) **in reasonable time frames;**
- For current landfills, **waste pre-treatment** (i.e. off-site reduction of the waste emission potential) **holds many advantages;**
- For **closed landfills** (or LF sections) a **twofold strategy** should be applied:
  1. Save **operation and energy recovery** through LFG extraction and utilization;
  2. After phase 1, the landfill should be **bio-stabilized** to approach **sustainability** in a reasonable time frame.

Conclusions (II)

- **Landfill aeration** has demonstrated to be a **suitable method** for accelerated and **sustainable emissions reduction;**
- The appropriate **aeration technology** has to be selected under consideration of site specific conditions **(e.g. waste mass & volume, LF height, waste moisture content, amount of bio-degradable organic carbon, etc.);**
- **Pre-test** should be **mandatory** in order to avoid incorrect design and operation problems;
- Aeration has to be accomplished by a reliable and comprehensive **monitoring program** (assessment of stabilization targets).

Conclusions (III)

- Landfill aeration can be **considered successful** if the following condition has been achieved:
  - ***90% reduction in the amount of biodegradable organic carbon***
- Under this condition it is **likely** that the following indications **have been achieved:**
  - ***Limited residual LFG production*** *(allowing for biological methane oxidation in top cover)*
  - *Widely* ***completed settlings***
  - ***Leaching potential*** *of landfilled waste is* ***low***

Conclusions (IV)

- Aerobically stabilised landfills require less efforts during the aftercare phase and might be earlier released form aftercare.
- Landfill aeration contributes to a reduction in GHG emissions, the methodology might be applied for CDM projects.
- There is an increasing number of full scale projects, particularly since 10 to 15 years ago.
- Positive experiences exist with bio-stabilized landfills in Germany, but also in many other countries.

Thank you for your attention!

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