Odour Emissions Assessment

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Odour Emissions Assessment

A Comparison of Odour Emission Rates from Three Different Types of Sewage Sludge Cakes (Bio-solids)

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1. Summary

Scope

One of the main utilisation routes for sewage sludge cake (or biosolids) is recycling to agricultural land as an organic fertiliser and a variety of regulations and codes of practice are in place to ensure it is undertaken safely. However, land applications can be problematic in terms of public perception if sludge recycled to agriculture generates ‘excessive’ odour emissions on farmland and particularly during and after land spreading.

This appraisal and report was commissioned by The James Hutton Institute to help assess the relative intensity of odour emissions which might be generated from three different types of sewage sludge cake during application to land and after spreading. Area specific odour emission rates expressed as European odour units per second per square metre of cake surface (ouE/s/m2) were measured from disturbed field- stored heaps of sludge cakes produced using the following three treatment systems:

1. Lime treated dewatered cake (LIMED)

2. Anaerobically digested and dewatered sludge cake (AD)

3. Anaerobically digested and dewatered sludge cake following pre-treatment by a thermal hydrolysis process (THP)

Findings

Effects of Sludge Cake Type - After taking account of potential measurement uncertainties and errors, odour emissions from the LIMED cake were in excess of an order of magnitude higher than from the AD and THP treated cakes.

These differences were also reflected in the indicative H2S emission rate measurements. The implications are that there are significantly higher risks of adverse odour emissions from land applications of LIMED cake than from applications of conventional AD or THP digested cakes.

Effects of Sludge Cake Age - The differences in odour emission rates between different sludge cake ages were not large in relation to the measurement uncertainties, although there was a trend for higher emissions from the most recently processed limed and conventional AD cake. Hydrogen sulphide emission rates for these two cakes were also higher from the most recently processed cake. This effect might be expected if there is a degree of additional biological or chemical stabilisation in cake which has been stockpiled for longer periods. On the other hand, NH3 emissions were slightly higher from the older limed and AD cakes than the more recently treated materials.

Implications for the biosolids industry

This work concerns a small number of different sludge cakes from a limited number of different sewage treatment works, but on the evidence of the measured emissions rates the following conclusions can be drawn:

1. There are much higher risks of adverse odour effects from the land applications of limed cakes than there are from the application of anaerobically digested cakes, either with or without preliminary thermal hydrolysis.
2. The substantially higher odour emission rates from lime treated cake demonstrate that much more rigorous odour mitigation measures must be used than for digested cake (with or without preliminary THP) if land spreading odour impacts are to be controlled or mitigated. Examples of such additional controls could include:
    a. Selecting application sites which are remote from residential settlements and housing,
    b. Restricting applications to small areas of land at any one time,
    c. Not applying limed cake to grassland or other areas which preclude ploughing-in or cultivation other than in very remote locations.
    d. Ploughing- in or incorporating more or less immediately after land spreading to minimise the surface areas of material exposed between spreading and incorporation.

2. Introduction

One of the main utilisation routes for sewage sludge cake (or biosolids) is recycling to agricultural land as an organic fertiliser and a variety of regulations and codes of practice are in place to ensure it is undertaken safely. However, land applications can be problematic in terms of public perception if sludge recycled to agriculture generates 'excessive' odour emissions during storage on farms (usually in field heaps), and particularly during and after land spreading.

This appraisal and report was commissioned by The James Hutton Institute to help assess the relative intensity of odour emissions which might be generated from three different types of sewage sludge cake during application to land and after spreading. Odour emission rates were measured from disturbed field- stored heaps of sludge cakes produced using the following three treatment systems:

1. Lime treated dewatered cake (LIMED)
2. naerobically digested and dewatered sludge cake (AD)
3. Anaerobically digested and dewatered sludge cake following pre-treatment by a thermal hydrolysis process (THP)

3. Sources of Sludge Cakes

The lime treated (LIMED) cake originated at the Scottish Water Kinneil Kerse works where it was treated with "Neutralac" liquid lime treatment for sanitisation. Measurements were carried out on field stockpiles on a farm in the Alloa area with the cooperation of Scottish Water and a local contractor.

The anaerobically digested and dewatered sludge cake (AD) was sourced from the Borders treatment plants at Galashiels and the measurements were carried out on field stockpiles on a farm in the St Boswell area with the cooperation of Scottish Water.

Anaerobically digested, thermal hydrolysis process (THP) dewatered sludge cake was sourced from the Seafield treatment plant (Edinburgh) and the measurements were carried out on field stockpiles on two farms in the Peebles area with the cooperation of Veolia and their local contractor.

The objectives were to sample two different ages of cake of each of the three types, although abnormal spring weather conditions created some constraints on the availability of cakes of differing ages.

Sampling was carried out on the 18th April (LIMED cake) and the 19th April 2018 (THP and AD cakes).

4. Methodology

4.1 Sampling

The measurement of odour emission rates was based on the collection of samples of odour in inert “plastic” sample bags from a ventilated hood placed over freshly exposed sludge cake. The objective of sampling material within the stockpile, rather than on the external surfaces was to sample cake which had not been ‘weathered’ by exposure to the atmosphere, as happens on the surface of stockpiles. The reasoning for sampling material within the stockpiles is that material within the body of the stockpiles represents the greatest mass of material exposed to the atmosphere during and after land application (spreading) which is when odour emissions are most critical.

When a suitable location was identified for sampling, the Scottish Water or Veolia contractor removed the surface layers of cake on the ‘side’ or ‘end’ of the stockpile with a loader or excavator bucket to provide a flat surface. A ventilated ‘Lindvall’ hood was then placed on the exposed surface of sludge cake in/on the stockpile and the hood ventilated with clean, odour free air provided by a battery powered fan and an activated carbon filter, as shown in Figure 1. The underside of the hood is equipped with a series of vanes to form seal on the cake and, most importantly, to direct the airflow back and forth across the cake to increase the flow path and to air speed at the cake surface (Figure 2).

Triplicate odour samples were collected from each cake sampled to help minimise the effects of measurement uncertainties in the odour measurement.

Figure 1 Odour Sampling with Lindvall Hood on relatively ‘friable’ THP digested cake.

Figure 2 Underside of Lindvall Hood showing internal vanes

The Lindvall hood was ventilated with clean air by a battery powered, portable fan (in the smaller aluminium case in Figure 1) blowing air through a carbon filter (in the larger aluminium case).

Once the hood was settled on the sludge cake, odour free (filtered) air was blown into the hood through the clear polyethylene terephthalate (PET) ducting. This air then traversed back and forth across the surface of the sludge cake under the hood, 'collecting' odour, and was then exhausted through ducting from the other end of the labyrinth formed under the hood by the vanes. The odour (air) samples were collected from this air stream off the hood through an inert sampling tube to new PET ('Nalophane') sample bags.

The sampling hood is shown in use on the three different types of sludge cake in Figures 3, 4 and 5 below.

These air samples were then used to measure the emissions of odour from the area of sludge cake covered by the sampling hood, by multiplying the odour concentration of the odour samples by the rates of ventilation through the Lindvall hood.

The sample hood was ventilated for 5 minutes before the first of each set of three samples was collected and then the three odour samples were collected sequentially, with each sample collected over a period of four minutes. Airflow rates exiting the sampling hood were measured with a vane anemometer and records were made of sampling times together with ambient air temperature, hood exit air temperature and sludge cake temperatures measured 50mm below the cake surface with an electronic thermometer.

Indicative measurements were made of ammonia (NH3) concentrations in air exiting from the hood during collection of the second odour sample for each cake using Kitagawa SD105 NH3 gas indicator tubes using either single or multiple full (100ml) or half (50ml) pump strokes as required. Ammonia has a relatively high odour detection threshold and as consequence is normally of very little consequence in ambient odours. Ammonia is known to be evolved at quite high rates during and immediately after lime treatment of liquid sludge and sludge cakes, that is within the confines of the treatment processing plant and buildings at sewage/sludge treatment works.

Figure 3 Older lime treated cake prior to hood being placed on cake.

Figure 4 Odour Sampling with Lindvall hood on relatively 'plastic' lime treated cake.

Figure 5 Odour Sampling with Lindvall hood on more ‘fluid” AD cake.

4.2 Odour Sample Analysis

The odour sample bags on site were transported to the UKAS accredited Silsoe Odours odour analysis laboratory and analysed within 30 hours of collection in accordance with the British/European Standard BS EN 13725. Odour concentrations were determined by presenting the samples to a panel of six human “sniffers” who sniffed the diluted sample at a range of dilution rates, starting at a high dilution ratio so that the panellists did not initially detect the odour and then sequentially decreasing the dilution ratios increasing until the odours were just detected. The presentations were carried out through a pair of sniffing horns, as shown in Figure 6, with the diluted sample randomly switched between the two sniffing horns for each different dilution presentation. The panellists selected which sniffing horn they thought was presenting the sample at each dilution rate and they also provided a response about the certainty of their decision, choosing from a ‘guess’, an ‘inkling’ or a ‘certain’ choice. The objective was to determine the number of dilutions of a sample which was required to just make the sample detectable to 50% of the panel of sniffers. This number (of dilutions) equates to an odour concentration in European odour units per cubic metre of air (ouE/m3).

The odour laboratory also measured hydrogen sulphide (H2S) concentrations in the sample bags using a

Jerome 631 H2S analyser. Jerome meters have some cross sensitivity to other compounds, so that the readings/results do not provide an absolute measurement of H2S, but they do give some indication of a) the extent to which there may have been septicity and anaerobic decay within the sludge cakes, and b) the propensity of the spread cake odours to have ‘drain’ or ‘faecal’ elements. The H2S measurements were indicative and not part of the Silsoe Odours UKAS accreditation.

Figure 6 – Odour analysis (nalophane sample bag in foreground)

4.3 Odour Emission Rate Calculations

The odour concentrations results determined by the odour analysis were then multiplied up by the measured airflow rate at the outlet of the Lindvall sampling hood to determine an odour emission rate, calculated as European odour units per second (ouE/s). Geometric mean odour concentrations were calculated for each set of three samples. Geometric means are used by convention in presenting the results of olfactory measurements because the human response to odours is approximately logarithmic.

The emission rate for each set of measurements was divided by the area of sludge covered by the hood to provide an area specific odour emission rate, expressed as odour units per second per square metre of sludge cake surface (ouE/s/m2). These units allow direct comparisons to be made between specific odour emission rates for each of the different sludge cakes and cake ‘ages’.

Similar calculations were also carried out for indicative area specific emissions of H2S and NH3.

5. Results

Area specific odour, H2S and NH3 emission rate data is summarised in Table 1. Figure 7 presents the comparative area specific odour emission rate data along with the 95 percent confidence intervals for the odour emission rates based on data provided in the BSEN 13725 standard in relation to olfactometric analysis as explained in section 6.1 below. Further details of sampling conditions and measurements are provided in Appendix 1.

Table 1 Comparative area specific emission rates. LOD = Limit of Detection

Sludge cake type	Approx. cake age	Odour emissions ($ou_E/s/m^2$) from geometric mean odour concentrations (with 95 percent confidence levels)	NH_3 emissions for second sample of each treatment ($mg/s/m^2$)	Mean H_2S emissions for each set of three samples ($mg/s/m^2$)
LIMED	8 weeks	**242 (153 to 382)**	0.171	0.00180
LIMED	4 weeks	**347 (219 to 548)**	0.118	0.00372
	Mean	**294 (186 to 465)**	**0.145**	**0.00276**
THP	12 weeks	**6.9 (4.4 to 10.9)**	0.216	<LOD
THP	4-5 weeks	**5.0 (3.2 to 7.9)**	0.128	<LOD
	Mean	**6.0 (3.8 to 9.4)**	**0.172**	**-**
AD	12 weeks	**9.0 (5.7 to 14.3)**	0.028	0.00003
AD	4-5 weeks	**15.4 (9.7 to 24.3)**	0.023	0.00025
	Mean	**12.2 (7.7 to 19.3)**	**0.025**	**0.00014**

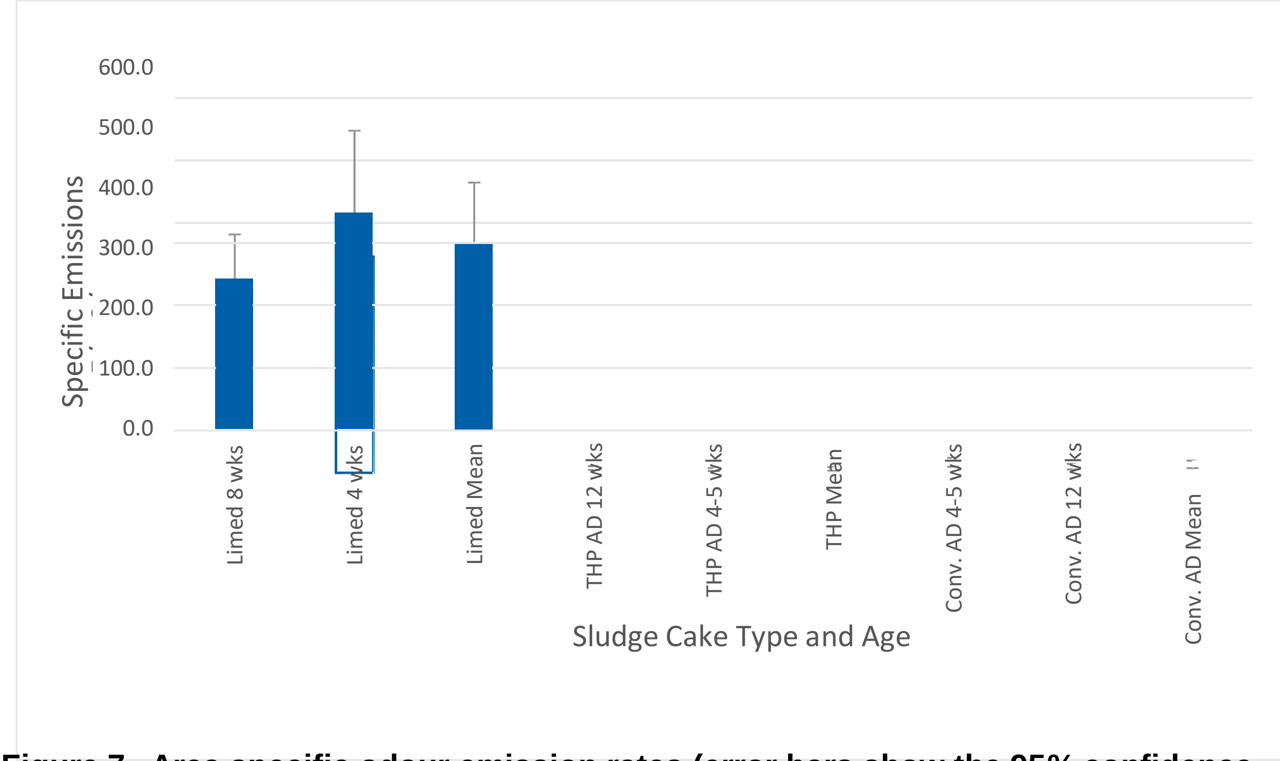

Figure 7. Area specific odour emission rates (error bars show the 95% confidence intervals)

6. Discussion of Results

6.1 Measurement Uncertainties & Other Variables

There are two main measurement uncertainties. The first factor is the repeatability of odour concentration determinations using olfactometric measurement with an odour panel. The precision limitations of olfactometric analysis data when interpreting monitoring data are set out in an annex to the BS EN 13725 standard. The 95 percent confidence limits for identical samples collected from the same source are set out in Table 2 below.

The data in Table 2 represents the limits of tolerable variations in measurement results for odour analysis in a laboratory complying with the BS EN 13725 standard and demonstrates that the 95th percentile range of "acceptable" results for a single sample covers a range of x 4.87 from the lower limit to the upper limit, whereas triplicate samples reduce this range to x 2.50. Long term practical experience is that such extremes in measurement results are extremely rare.

The results reported in Table 1 and Figure 7 above include 95 percent confidence limit values for the area specific odour emission rates based purely on these factors for triplicate samples, that is ignoring other variables, and also based on the simplistic assumption that all three samples collected from each sludge cake treatment were of identical odour concentrations. However, it is acknowledged that this may notbe entirely true if there were some progressive reductions in sludge cake surface emissions through even the short sampling periods required to collect three samples.

Table 2. The 95 percent confidence intervals for analysis of odour samples with an expected odour concentration of 1,000 ou_E/m^3 (BS EN 13725 Annex F)

Number of Identical Samples Analysed	95% confidence limits for an expected odour concentration of 1000 ou_E/m^3		
	Lower limit	Expected	Upper Limit
1	453	1,00	220
2	571	1,00	175
3	633	1,00	158
4	673	1,00	148
5	702	1,00	142
6	724	1,00	138
7	741	1,00	134
8	756	1,00	132

The other potentially significant measurement uncertainty concerns the ventilation rate of the Lindvall hood because of factors including the ‘porosity of the cake and the seal between the sampling hood and the cake material, both of which may result in some leakage from the hood. External wind speed may also affect the rate of ventilation because of wind effects on the “layflat” tubing used as inert ducting. For the sake of consistency, all airflow measurements were made at the exit from the hood to reflect the actual ventilation rate of air through the entire length of the air flow path through the hood. It is estimated that these measurement uncertainties could account for differences of up to factors of x2 to x5 at the extremes of the measured emission rates.

It is also noted that the measurements reported here represent the sludge cake outputs from three example works. The composition of sludge cakes, and the resulting emission rates from cakes from other works may be quite different even with the same treatment processes.

6.2 Effects of Sludge Cake Treatments

After taking account of potential measurement uncertainties and errors, there were materially higher odour emissions from the limed cake than from the AD and THP treated cakes, with emissions in excess of an order of magnitude higher than the AD and THP digested cakes. These differences were also reflected in the indicative H2S emission rate measurements. The implications are that there are significantly higher risks of adverse odour emissions from land applications of limed cake than from applications of conventional AD or THP digested cakes. These findings are consistent with ADAS experience of measurements made during commercial consultancy work with limed and THP cakes elsewhere. The low odour emissions from AD and THP are perhaps not surprising because limed cake does not undergo the significant biological degradation which does occur in conventional anaerobic digestion, and particularly in the more destructive combination of THP and AD processes.

No H_2S was detected in the THP digested cake and odour emissions were approximately half the rate of conventional AD cake, although these approximate factor of two differences may not be significant in relation to the measurement uncertainties.

Ammonia emissions were similar for the limed and THP digested cakes, but materially lower for the conventional AD cake. Elevated NH_3 emissions could be expected with limed cake treatment because of the nature of the reactions caused within the cake by lime treatments. The nitrogen content of the pre- processed sludge cake is also likely to influence NH_3 emissions from the resulting cakes.

6.3 Effects of Sludge Cake Age

The differences in odour emission rates between different sludge cake ages were not large in relation to the measurement uncertainties, although there was a trend for higher emissions from the most recently processed limed and conventional AD cake. Hydrogen sulphide emission rates for these two cakes were also higher from the most recently processed cake. This effect might be expected if there is a degree of additional biological or chemical stabilisation in cake which has been stockpiled for longer periods. On the other hand, NH_3 emissions were slightly higher from the older limed and AD cakes than the more recently treated materials.

6.4 Context of Odour Emission Rates

The measured odour emission rates reported here can be compared with data from similar measurements made on other materials, including compost and other sewage-related materials.

In relation to composting and mature compost, the South West Industrial Crops Environmental Body[1] sponsored a research project to measure odour emissions from composting process and compost. The findings were that odour emission rates from the surfaces of various feedstocks and stages in the composting process extend over a very wide range.

At one extreme odour emissions from predominantly green waste composting on one site, or from green waste composting with some wood and municipal feedstock based materials on a second site, were typically between 20 and 40 ouE/s/m2 and less than 20 ouE/s/m2 respectively. At a third site, where more
putrescible vegetable and plant materials were being composted, significantly higher emissions were measured on the feedstock materials and disturbed windrows/stockpiles, with odour emission rates up to 1,244 ouE/s/m2.

Higher, short-term emissions do occur during, and after turning with emission rates up to factors of 10 to

20 times higher during and after turning than from undisturbed windrows. Mature, well made compost was shown to be less odorous, with area specific emission rates comparable to those reported here from AD and THP cakes at around 2.5 ouE/s/m2. This data suggests that emission from land applications of AD and THP cake will be similar to those from stable/mature compost, and that emissions from limed cake are substantially higher than from compost.

[1] South West Industrial Crops Ltd “Bioaerosol Monitoring and Dispersion from Composting Sites” (2005)

In relation to sewage sludge and sludge cake the United Kingdom Water Industry Research (UKWIR) organisation has provided examples of "estimated" odour emission rates set out below in Table 3 in a technical guidance document2[2].

Table 3. UKWIR Estimated Odour Emission Rates

Material & condition	Odour Emission Rates (ouE/s/m^2)			
	Low	Typical	High	Very high
Quiescent raw, liquid sludge tank or lagoon	7.9	40	80	160
Raw liquid sludge with some disturbance	140	710	1,400	2,800
Digested sludge tank (liquid)	14	71	280	1,400
Sludge cake	0.8 (old, digested)	62 (fresh, digested)	80 (raw)	800 (during disturbance)

The UKWIR "old, digested" sludge cake emission rate data is quite consistent with the measured emission rates reported here for AD and THP cake, but does suggest that fresh digested cake may be more odorous than the rates measured on the field stockpiles.

The substantially higher measured emission rates for LIMED cake reported here (242 to 347 ouE/s/m^2) are at the upper end of UKWIR emission rates for sludge cake and comparable with emission rates for some
categories of liquid sludge.

[2] Odour Control In Wastewater Treatment - Technical reference Document, UKWIR, 2001

6.5 Implications of results for the biosolids industry

This work concerns a small number of different sludge cakes from a limited number of different sewage treatment works, but on the evidence of the measured emissions rates the following conclusions can be drawn:

1. There are much higher risks of adverse odour effects from the land applications of limed cakes than there are from the application of anaerobically digested cakes, either with or without preliminary thermal hydrolysis.
2. The substantially higher odour emission rates from lime treated cake demonstrate that much more rigorous odour mitigation measures must be used than for digested cake (with or without preliminary THP) if odour impacts are to be controlled or mitigated. Examples of such additional controls could include:
   a. Selecting application sites which are remote from residential settlements and housing,
   b. Restricting applications to small areas of land at any one time,
   c. Not applying limed cake to grassland or other areas which preclude ploughing-in or cultivation other than in very remote locations.
   d. Ploughing- in or incorporating more or less immediately after land spreading so that only minimal areas of spread material are exposed between spreading and incorporation.

7. Appendix 1 Sampling Data

Date	Cake type & approx. age	Sample ID	Sampling times	Odour Concentrations 3		Hood Ventilation rate (m^3/s)	Emission rate ($ouE/s/m^2$)	H_2S Conc. (ppm)	Mean H_2S Emission 2	NH_3 Conc. (ppm)	NH_3 Emission ($mg/s/m^2$)	Air Temp. off hood (^0C)	Cake Temp (^0C)	Amb. Temp (^0C)
				samples	Geo. Mean									
18/04	LIMED 8 weeks	A1	11:05-11:09	21,264	28,007	0.0084003	**241.6**	0.17	0.00180	28	0.171	14.2	10.7	14.9
		A2	11:10-11:14	26,880				0.15						
		A3	11:15-11:20	38,436				0.12						
18/04	LIMED 4 weeks	B1	11:37-11:42	32,736	29,102	0.0116045	**346.7**	0.29	0.00372	14	0.118	16.4	16.8	
		B2	11:43-11:48	36,288				0.20						
		B3	11:49-11:53	20,748				0.17						
19/04	THP 12 weeks	C1	09:28-09:32	964	726	0.0092663	6.9	0.000	0	32	0.216	16.1	9.2	15.9
		C2	09:33-09:37	622				0.000						
		C3	09:38-09:43	639				0.000						
19/04	THP 4 to 5 weeks	D1	10:17-10:21	724	722	0.0067549	5.0	0.000	0	26	0.128	18.7	10.7	15.8
		D2	10:22-10:26	860				0.000						
		D3	10:27-10:32	604				0.000						
19/04	AD 4 to 5 weeks	E1	13:08-13:12	3,949	4,325	0.0034641	15.4	0.066	0.00025	9	0.023	18.3	10.0	17.8
		E2	13:13-13:17	4,424				0.047						
		E3	13:18-13:22	4,631				0.034						
19/04	AD 12 weeks	F1	14:04-14:08	726	920	0.0095550	9.0	0.003	0.00003	4	0.028	18.8	9.2	18.2
		F2	14:09-14:14	972				0.002						
		F3	14:15-14:20	1,103				0.002						

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