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Contribution of waste management companies towards a flexible energy system using sector coupling

Contribution of Waste Management Companies towards a Flexible Energy System Using Sector Coupling

Abstract

To research how waste management companies can support load flexibility, recycling plants were analysed on their potential for taking part in the control power market. The results show that the studied plants are generally suitable to supply control power. As contribution to increase the load flexibility potential of the plants the electrification of waste collection vehicles to hybrid or full electric vehicles is examined. Moreover, the goal is to increase the economic feasibility of this kind of vehicle types to make a comprehensive power engine transition of the fleet attractive at an earlier stage.

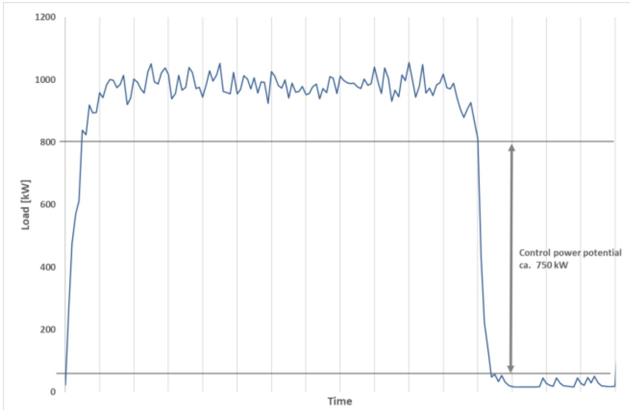
1 Introduction

The transition to an electric power generation based on renewable energy faces many challenges. Due to fluctuation of important renewable energies, e.g. wind and solar power, it is necessary to stronger correlate demand and supply. The German Federal Ministry for Economic Affairs and Energy states that the increasing electrification of mobility and heating provision '*... requires increasingly aligned operation between regional and nationwide electricity grid operators, generating plants and consumers, in order to continue to make the energy system more flexible*.' [1, p. 47]. One option to put this into practice is load management of industrial consumers. Several studies looked at this specific issue. For example, one of the so-called Kopernikus-projects for energy transition, 'SynErgie', summarised the results of several studies on load flexibilization of several raw materials industries in Germany, e.g. glass and cement production [2].

As part of the 'Smart energy showcase – digital agenda for the energy revolution'(SINTEG)-projects flexibility options in different areas in Germany are analysed [3]. In the North-Eastern region the project 'WindNode' identifies and characterises flexibility options and tests their use [4]. Besides day-ahead options the project also looks at the concept of intraday load flexibilization offers that are less established for commercial power consumers. On the corresponding flexibility platform offers for four times 15 minutes-blocks can be submitted up to two hours before the corresponding load management. One aspect of the project is to identify necessary pre-qualifications for their intraday market. These must satisfy the needs of the grid operator as well as minimise the restrictions for potential participants in respect to minimum demand power and minimum demand to be offered. [5] If the concept proves to be viable, new options arise for consumers that do not fulfil the requirements of the tertiary control power market.

Rising demand for flexibility and more options to offer it increases the relevance for research on demand side management of different industries. Not investigated yet is the potential of the recycling industry and it's more than 15,800 plants all around Germany to contribute to grid stability and load flexibilization [6]. Risen statutory recycling quotas lead to stricter selectivity requirements. This increases the complexity and energy demand of waste sorting plants. At the same time an economic operation of downstream waste processing plants, e. g. for plastics compounding, becomes more important as the amount of sorted waste increases. Therefore, a suitable demand side management and the participation in energy markets becomes more and more of interest for recycling companies. For this, sector coupling is an important support. It can increase flexibilities and therefore promote the participation in control power markets. Additionally, power peaks can be levelled out without burdening the electricity grid. From a sustainability point of view sector coupling can contribute to a higher share of renewables in the energy consumption of waste treatment plants.

Sector coupling is discussed mainly in the context of Power-to-X and CO_2 reduction by integrating renewable energies. However, this also leads to more stress for the power grid. Demand side management is one option to reduce this stress, including load management for e-drive vehicles. At the moment there are still high investment costs of electric heavy-duty vehicles. For example, the Ger-



man government funded a study on electric waste collection vehicles, which proved not to be an economically feasible option [7]. It can be assumed that reduced battery investment costs will have a positive effect in the future. The introduction of electric series vehicles for heavy-duty together with subsidies might lead to high-volume production of corresponding batteries in future. This will have a positive effect on battery prices. However, an extension of the vehicle application range and the introduction of new revenue options can facilitate broader market chances.

The project ‘EnvirA-Management4Grid – Prozessbasierte Lastmanagementpotentialbestimmung umwelttechnischer Anlagen zur Verbesserung der Netzstabilität’ (Process-based Identification of Load Management Potential of Waste Management Plants for Increased Grid Stability) analysed the potential of different waste treatment plants to contribute to load flexibilization. Exemplified plants operated by the ALBA Group were examined. As part of the study ‘Netzdienliche Integration hybrider Entsorgungsfahrzeuge’ (Grid-beneficial Integration of Hybrid Waste Collection Vehicles, abbr. *Ihenfarm*) it is researched, whether this flexibilization can be increased by combining the plant load with the power of electric or hybrid waste collection vehicles. A lightweight packaging sorting plant is used as example plant for this coupling. The research also includes an analysis on the influence of such a measure for the economic feasibility of e-drive waste collection vehicles and their contribution for emission reduction in urban areas. Following, the main results concerning load management of a lightweight packaging recycling plant, the transition to an electric/hybrid waste collection vehicle and possible links are presented.

2 Load Flexibility of Recycling Plants

Among the seven processes analysed within the EnvirA-Management4Grid-project, lightweight packaging sorting plants proved to be especially interesting concerning flexibility options. They can have a sorting capacity of more than 100,000 t/a and a power consumption higher than 1,000 kW. Small plants with a capacity less than 10,000 t/a are in operation. However, over recent years there is a trend towards larger plants going along with lower specific sorting costs. As a result, the number of plants sorting most of the waste decreases. In 2010 almost 90% of the total lightweight packaging waste was processed in less than half of total number of respective plants [8]. Recent announcements concerning new plant installations show that this trend is still ongoing. Therefore, the research focus was on sorting processes in high capacity plants. The potential flexibility volume was examined and the necessary prerequisites were identified. First, potential flexibilities were analysed using real load data. Figure 1 illustrates an example for this analysis. It shows that a flexibility of 750 kW is available theoretically. However, it was necessary to look at the process in more detail to evaluate the real load shift potential.

For this the load profiles of the plants and the respective operation units were modelled. Essentially, there are three units: sack opener, sorting and compacting. Between the sorting and compacting unit buffer storages are used to collect the sorted waste. Further explanations on the structure of lightweight packaging sorting plants are described inter alia by Cimpan et al [9].

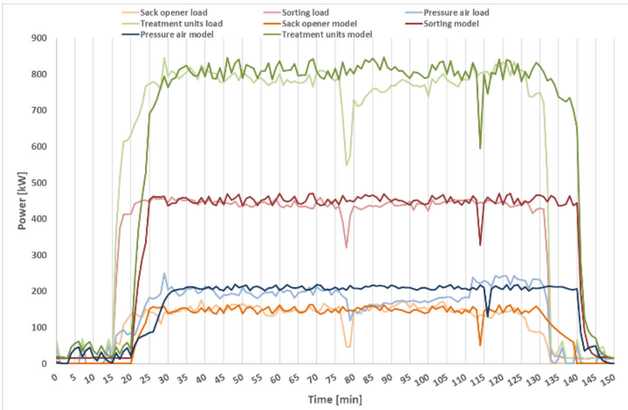


Figure 1 Load profile for a lightweight packaging recycling plant and control power potential

Besides the three operation units mentioned above a pressure air unit used for near-infrared sorting is relevant for load management. The start-up of light weight packaging sorting plants takes place in the reserve direction of flow and needs up to ten minutes. The individual start-up time of each unit differs depending on its aggregates. The above-mentioned units can be divided into two independent parts: treatment (sack opener, sorting, pressure air) and compacting. The autonomous operation is due to buffer storages for each component after the sorting process, which decouple the process parts. Each storage is linked to a specific compactor and for each compactor there are multiple storages. The order of emptying these storages is given by the respective filling level. Therefore, the load profile of the compactors was modelled by taking into account the filling level of the storage that is subject to the corresponding component flow. A challenge for the model was the low resolution of the mass flow. Mass data is available for every eight-hour-shift. This restricts detailed modelling of fluctuation in the load that is especially relevant for the pressure air unit.

The analysis of the load profiles shows that the load for the compacting unit is very fluctuating compared to the treatment units. This is due to the difference in energy needed for compacting different components Therefore, for this partial process the relation between load and mass was examined for each sorting product. For the treatment units there is a linear relationship between load and mass flow. The corresponding function was identified using the least-square-method. The parameters that were calculated are the specific energies of different lightweight packaging components and impurities. The mass flow composition was also modelled using given data for the treated mass per shift and its composition. Inhomogeneities were included by usage of a randomiser. The model was validated using real load data. Working breaks were removed from the data set. Figure 2 compares the real load profile and the modelled ones for the treatment units, the compacting unit and the pressure air unit. Overall the model works well, however, higher load deviations due to malfunction or similar issues cannot be factored in by the model.

Figure 2 Real and simulated load profiles for sack opener unit, sorting unit, pressure air unit and all treatment units

The compacting units were analysed for each sorted component and the load was modelled by putting it in relation to the respective pressing time. However, the load also depends on other factors, e.g. the overall density of the material. As these factors are fluctuating, it was not possible to model the process exactly. Since the compacting unit is only responsible for around 10 % of the total load, these deviations do no factor in on a large scale.
Possible scenarios for offering flexibilities were discussed taking into account framework conditions and process flows. To offer tertiary control power in Germany, the respective plant must be able to run a double peak load profile. This means it must handle two calls for flexibilities for 30 minutes each and a break in between with the same length. The time for activation and deactivation of the plant must not exceed 15 minutes. As lightweight packaging sorting plants are able to start up and shut down in less than ten minutes this requirement can be fulfilled. However, load fluctuation due to inhomogeneous materials must be compensated. Figure 3 illustrates the load profile development in case of a call for tertiary control power.
It is shown that for lightweight packaging recycling plants the participation in the control power market is only possible by pooling the flexibilities as a single plant cannot guarantee the required minimum load and duration of provision. However, this might change in future with the development of new market schemes. Therefore, different scenarios were analysed.

1. Treatment processes are shut down
2. Treatment processes are run in partial-load operation
3. Treatment processes are run in partial-load operation and compactors are shut down
4. Complete plant is shut down

A major criterion for the plant operator is that the daily mass flow must not be changed by offering flexibilities. This proviso was factored in for the evaluation of each case. Additionally, the first two scenarios require the feeding of the compactors by buffer storages during the call for flexibilities. Therefore, flexibility can only be offered if there is sorted waste available for compacting. For the first scenario this is a relevant restriction that reduces the time frame to shift the load to less than 30 minutes. The maximum flexibility available is 750 kW. For scenario 2 this restriction does not apply in the same magnitude as the processes run with a partial load of 60 %. In this case it is possible to offer negative control power for more than four hours without any major issue for the daily mass flow. Thereby, the requirement to take part in the control power market as well as the one set by the operator is fulfilled. Flexibilities up to 200 kW can be offered. However, lead and follow-up time must be considered in practice. For scenario 3 the maximum flexibility given in the second scenario is increased by shutting down the compactors. Again, the capacity of the buffer storages limits the possible time frame. In this case, they are filled to the maximum after 60 minutes latest as no sorted waste is fed to the compactors. During the interval the flexibilities increase up to 830 kW. The same applies to scenario 4. However, even though the capacity of the buffer storage is no limitation, the daily mass flow, that needs to be processed, is. Because of that, the scenario is only applicable for a maximum of one hour. Figure 4 shows the development of the entrance storage over time for different durations of call for tertiary control power.

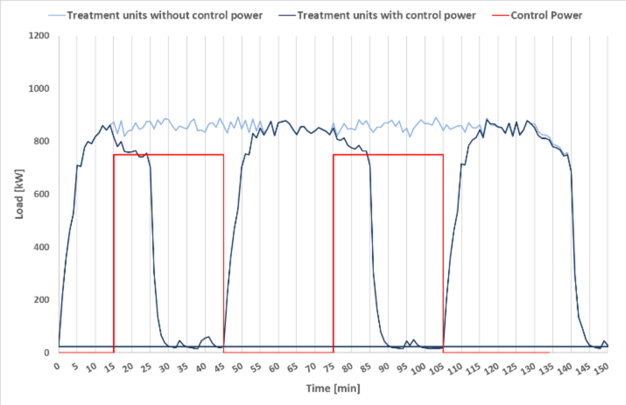
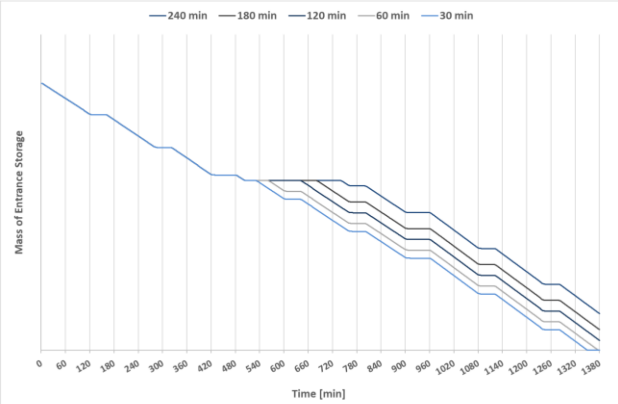


Figure 3 Comparison of load profile for treatment units with and without call for tertiary control power and course of this control power

One aspect that applies to all scenarios is the issue of working breaks required by German working regulations and those used for cleaning and maintenance after each shift. There are nine breaks and meanwhile all operation units are reduced to basic load. Therefore, irrespective of technical limitations it is not possible for a plant to take part in the existing control power market on its own. Another challenge for lightweight packaging recycling plants in relation to flexibilities is the above-mentioned dependencies of load and mass composition, especially concerning the compacting process. It is not possible to analyse this composition at the beginning of the treatment process. Therefore, small load fluctuations cannot be avoided, in case of partial operation and not a complete shut-down. However, as the load depends even more on the mass flow, it is of more relevance to control the mass that is transferred from the entrance storage to the belt conveyor. Therefore, for the implementation of a load management system it is necessary to regulate the mass flow accordingly.

Figure 4 Filling level in entrance storage over a day for calls for tertiary control power over different timeframes



In general, lightweight recycling plants have a high potential to offer flexibilities to power grid operators. The main challenges are operation breaks that disturb the load management, load fluctuations due to changing waste compositions and restrictions in taking part in the tertiary control power market as the required minimum flexibility of 1,000 kW is not available. Some of these aspects might not be as relevant in future if new markets concepts are realised. Another option is to find new ways to overcome these challenges. The operation of recycling plants usually involves the administration of a waste collection fleet. Therefore, for this application coupling the electricity and mobility sector is a logical step.

3 Electric Drives for Waste Collection Vehicles

A key aspect of the project Ihenfarm is the analysis if and how grid-beneficial integration of hybrid or full electric waste collection vehicles and their storage systems is possible. This includes the coupling with a recycling plant, exemplified by a lightweight packaging plant. Furthermore, it is evaluated whether the vehicles and their charging stations can be coupled with a thermal waste treatment plant. The usage of the transported waste as solid fuel to generate electric power is an attractive contribution for grid stability and increases the economic efficiency of the plant. Additionally, charging the battery of the waste collection vehicles closes the cycle of materials and energy. The conversion to hybrid or full electric waste collection vehicles aims to reduce different kind of emissions within Berlin city. Therefore, the potential to reduce these local emissions are analysed for all existing vehicles in the city and put in relation to other emission sources. All results are integrated in an economic analysis.

In the last years several pilot projects concerning electric or hybrid waste collection vehicles were implemented in different cities worldwide (e.g. [10], [11], [12], [13]). The focus was on hybrid vehicles as the investment costs for electric ones are still high now. For this kind of vehicle either only the upper body with the hydraulic systems are electrified or additionally the combustion engine system is combined with an electric one. For 2019, mainly electric waste collection vehicles are going to be launched in the markets, e.g. by Volvo ([14], [15]) and Renault ([16]).

One challenge for the simulation of heavy-duty vehicles is the modelling of the battery pack. The battery model developed for this project describes relevant battery parameter to simulate power flows inside an electric waste collection vehicle. It follows a datasheet-based empirical approach:

- Dissipation of charging and discharging process
- State of Charge (SoC)
- State of Health (SoH)
- Battery temperature

The dissipation is determined by the charge and discharge efficiency that is defined by a simple stationary equivalent circuit model. The charging process includes power-dependencies, the discharge process temperature- and power-dependencies respectively. The SoC is determined using an off-line book-keeping method. It follows an energy balance that considers charging and discharging dissipation, self-discharge effects and current battery capacity. The charge and discharge limits are power and temperature dependent to define the useable battery capacity range.

The thermal model to describe the battery temperature considers heat flows by ohmic losses and the battery cooling system. An infinitive thermal conductivity and thereby a homogenous temperature distribution within the battery is assumed. [3]. These assumptions are used in several thermal battery models (e.g. [8], [9]). The percentage periodic power loss is based on a cycling-counting-method by Wang et al. [4]. The percentage calendrical power loss is determined using the model by Grolleau et al. [5].

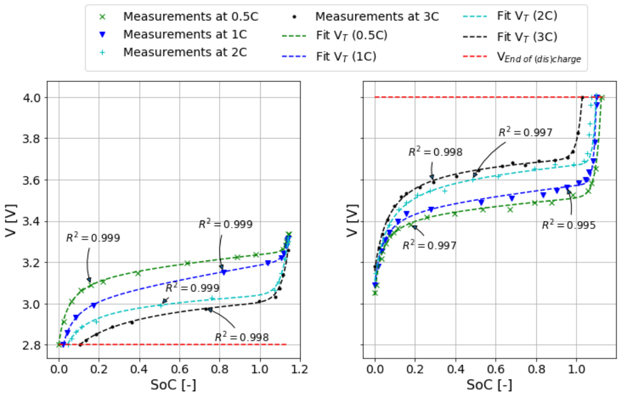


Figure 5 Approximation of power-dependent charging- and discharging terminal voltage development for a LFP cell

The parametrisation of the stationary battery model rests upon the charging- and discharging terminal voltage development of a lithium-iron-phosphate (LFP) cell.This kind of cell is more common for the electrification of the upper body of a waste collection vehicle. The terminal voltage development is approximated using the equation by Tremablay et al. with C-rates higher 0.5 C. This meets the typical range of use for electric mobility [6].

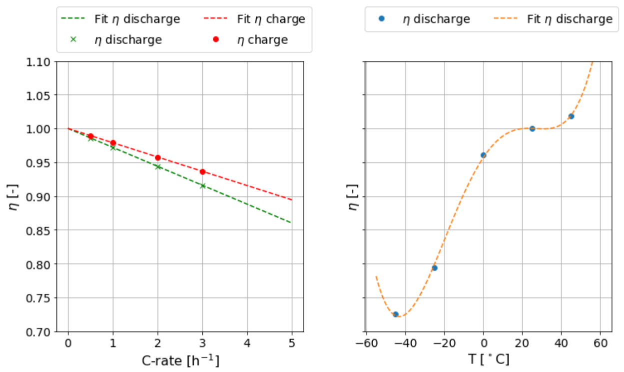


Figure 6 Efficiency based on power and temperature for a LFP cell

With the results for the power-dependent (figure 5) and temperature-dependent terminal voltage development the battery internal resistance can be modelled. The dissipation and efficiency can subsequently be calculated following the ohmic law (figure 6).
Using the approximated end-point voltage and a safety factor of 10 % the power- and temperature dependent charging and discharging limits for the cells are determined (figure 7,8). To include all results a reference point is used (25 °C and 0.5 C).

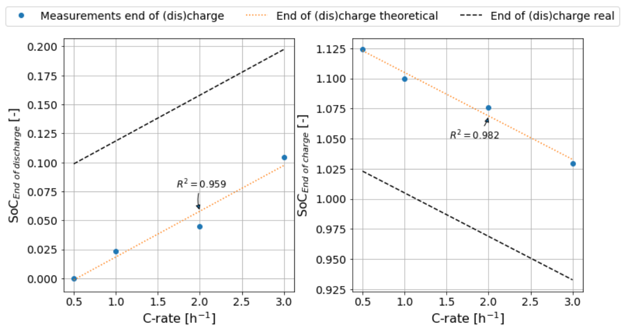
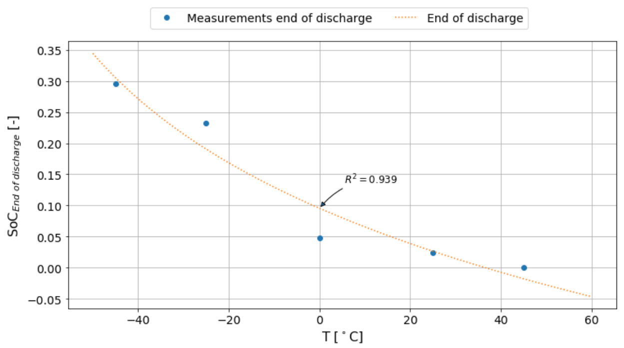


Figure 7 Power-dependent charging and discharging limits

A hybrid waste collection vehicle will be simulated by coupling the battery model with a model of the hydraulic system used to toss the waste on the load floor. For that the corresponding drive will be modelled taking into account the required load for the process and the number of times one cycle is executed per collection area. For a full electric vehicle an additional drive train model is implemented. Due to the large number of stop-and-go during a collection ride one focus lies on the load behaviour at start and slow-down, including recuperation of braking energy. Also, the increasing weight of the vehicles during the ride must be considered.
The hybrid and full electric waste collection vehicle models are used to simulate how the flexibility of recycling plants can be increased by integrating these vehicles. As these vehicles are stationed at the fleet basis during the night and in times they are not in use they are available for this purpose. Condition is that the vehicles are ready to start a new waste collection shift according to schedule. The battery model is coupled with a model of a lightweight recycling plant. Relevant is to examine, how the utilisation of the batteries can unite the requirements of the power control market and the ones given by the plant operators. This mainly concerns issues like the overflow of material storages and process of the given daily waste feed in time.

Figure 8 Temperature-dependent discharging limit



Besides coupling the waste collection vehicles with recycling plants, another option is to connect them with thermal waste treatment plants. These plant types are interesting in terms of sector coupling as the resulting heat is converted in electricity by an on-side power plant. First analyses show that they are suitable to offer different kinds of control power. However, these plants do not operate continuously, but are shut down for some time during the weekend. The batteries might be able to compensate these shut downs. This especially applies since the waste collection vehicles are not in use during the weekend. Therefore, the operating time of the vehicles can be increased. Additionally, combining the thermal waste treatment plant with a battery charging station can have positive economic effects. The existing infrastructure and the billing modalities concerning the supply of electric power to the grid must be analysed. Depending on that the use of the converted energy to charge the batteries of the waste collection vehicles might reduce taxes and fees.

4 Next Steps and Outlook

While the battery was modelled using LFP cells, for full electric vehicles this type of material is not favourable. Therefore, the existing model will be extended by introducing a Lithium-Ion-cell, called LTHP, that was specifically developed for drive trains [22]. Also, the safety factor used in the model will be discussed with battery manufactures to ensure realistic values. The simulation of collection rides significantly depends on realistic data concerning energy consumption, transported mass and number of stop-and-go. The more detailed this data the better the simulation. However, to transfer the results to other applications and to consider corporate restrictions concerning data disclosure the given data must be adjusted. To balance accuracy and transferability will be a major focus.

Once this simulation is completed, charging concepts will be developed. This includes link-ups with the exemplary lightweight-packaging plant and thermal waste treatment plant, but also options for interchangeable battery systems. The concepts encompass technical as well as economic and environmental aspects. Besides investment and operational costs on the one hand and revenues from the energy market on the other, one focus will be on long-term financials. This includes earnings derived from selling the vehicles after their regular life time for further use as well as vending the battery for a second lease of life. Several companies are involved in projects concerning heavy duty vehicles battery-recycling, opening new markets. Another aspect to consider will be, how to apply the results in real-life operation. This especially applies for solutions that implies more effort for the plant operators in comparison to current operations. The successful implementation significantly depends on the cooperation of employees on-site.

5 Conclusion

The results show that there is a huge potential for the recycling industry to benefit of the risen demand for flexibilities. This especially applies, if new schemes for control power markets are introduced. At the same time the electrification of waste collection vehicles can be economically sensible if battery prices fall and there is a more efficient utilisation of the vehicles. Thereby, the recycling industry cannot only profit economically but it can contribute to a safe introduction of a higher share of renewable energies in the power grid and decrease of local emissions.

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