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Carbon Intensity of Harvesting Residue-Based Electricity: Case Study of Eversource Energy

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Introduction

This case study was undertaken at the request of the Biomass Power Association for the purpose of analyzing the scenario in which harvesting residues are used for generating electricity at a 50 MW biomass fueled electric generating station instead of being left to decay.[1] This facility was used as a data source to develop the carbon intensity of electricity generated aspect of this study.

The objectives of this study are: a) determine the carbon intensity of electricity generated using harvesting residues and compare it with that of natural gas-based electricity generation; b) to examine time path of the carbon intensity of bio-electricity; and c) analyze critical parameters that affect the carbon intensity of bio-electricity over time. The harvesting residues considered here are obtained as a by-product of harvesting operations conducted for supplying roundwood products to nearby lumber and paper mills. In the absence of collection for electricity generation, harvesting residues would be left on the forest floor to decay since they are of no commercial value. Following each harvest, trees are assumed to grow back naturally. It is assumed that a stand is partially harvested every 25 years in the central New England Region in this study.

Key underlying assumptions of our analysis are that the collection of harvesting residues does not affect forest harvesting and management operations, the rotation age of forests, forest growth, and carbon storage in standing harvesting residues or soil carbon stocks; this implicitly assumes that harvesting of tops and limbs and non-merchantable biomass would have occurred anyway (whether or not it was used for bioenergy or left in the forest). We are also assuming that the demand for harvesting residues for electricity generation does not affect the production of conventional forest products or lead to any changes in an area under forestry cover over time.

Production of Harvesting Residues

We assume that there is 14.12 metric tons per hectare of chipped harvesting residues available every 25 years (Kingsley, 2017). The chipped harvesting residues are loaded on a truck and transported to the power plant. Since the forest regrows naturally, no silviculture or energy inputs are needed to produce the trees. Diesel is consumed during the process of felling and skidding the logs. Diesel is consumed in chipping and transporting the harvesting residues from the forest to the power plant; the latter depends on the capacity and fuel economy of a truck and hauling distance. We use data on fuel consumption during the process of harvesting and skidding the logs, chipping of harvesting residues, and transporting chipped harvesting residues to estimate the carbon emissions per metric ton of delivered harvesting residues (Table 1). We used values reported in Table 2 to obtain carbon emissions per unit of electricity (kWh) generated from the incoming chipped harvesting residues.

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[1] Data for the Study was provided by Eversource Energy's Schiller Station, located in Portsmouth, NH. The facility has a total capacity of 50 MW but typically supplies the electric grid with a net output of 43 MW.

Table 1: Parameters for estimating C emissions related to production and transportation of harvesting residues from a harvesting site to the 50 MW biomass plant.

Parameters	Values
Harvesting residues availability	14.12 Mg/ha (every 25 years)
Annualized harvesting residues availability	0.56 Mg/ha/year
Diesel consumption (logging and skidding of logs)	5.42 liters/Mg
Diesel consumption (chipping of tops and limbs, low quality tress)	1.25 liters/Mg
Payload of a logging truck	28.12 Mg
Average hauling distance	80.5 km
Average fuel economy	1.87 km/liter
Carbon released due to diesel consumption	0.73 kg C/liter

Table 2: Parameters for determining C intensity of generated electricity. Natural gas power plant is assumed to have a conversion efficiency of 50% implying that 81.6 grams of C is emitted per unit of electricity generated.

Parameters	Values
Biomass Power Plant[2]	43 MW
Capacity Utilization	85%
Conversion Efficiency	24.6%
Calorific Value of Chipped Biomass	9.9 MJ/kg

Forest Carbon Stock

The removal of harvesting residues for electricity generation reduces carbon stock in the forest at the time of the harvest. However, it also prevents carbon emissions that would have occurred due to decaying harvesting residues in the forest over time[3]. Assessment of the impact of harvesting forest biomass on forest carbon stock depends on the scale of the analysis. A stand-level view of the forest focuses on changes in carbon stock at a single site and follow changes in biomass on that specific site as it is harvested and regrows over time. Each site is treated *independently* of other sites in the forest and the contribution of each site to the carbon cycle is considered individually for that site. An alternative approach is to take a landscape level view of the forest that considers a forest as being managed to generate forest biomass (pulpwood, sawtimber) and resulting harvesting residues continuously to feed an industrial operation (Lamers and Junginger, 2013). We assume that a forest product industry in the region is relying on a continuous supply of forest biomass. In this case, it is more appropriate to consider the impact of annual removal of harvesting residues on the entire region using a landscape level analysis than a stand level analysis.

With a landscape view of the forest and a 25-year rotation cycle, a minimum of 25 units of land would be needed to provide a continuous supply of harvesting residues annually to the 50 MW biomass power facility. In this case each hectare is managed as a part of a 25-hectare landscape and not independently of the other sites. One hectare is harvested each year and it starts to grow and accumulate carbon soon after. The other 24 hectares are at various stages of regrowth. Under this continuous forestry operation assumption, it is appropriate to consider the carbon in the standing trees as being recycled (contemporaneous) carbon since the loss of carbon due to

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[2] The facility has a total capacity of 50 MW but typically supplies the electric grid with a net output of 43 MW.

[3] Residues left in the forest are assumed to follow a negative exponential decay function with a 15-year half-life.

harvest in one section is being accompanied by growth of trees in other sections during the harvest rotation (Dwivedi et al. 2014; Lamers and Junginger, 2013). Under the view, the carbon stock in the standing biomass on a 25-hectare wood basket is maintained at a constant level if the amount of harvest, the age of harvest, and forest management practices do not change over time. Therefore, the removal of harvesting residues will not affect the amount of carbon in the standing biomass. It will however affect the total amount of carbon stored in the form of residues in the forest. We describe that process below.

Under the landscape level view, a constant amount of harvesting residues are added to the forestland each year. These residues are subject to a time dependent decay path. When left unharvested, these residues begin to accumulate over time in a continuous manner and the carbon emissions from their decay grow first and then starts to stabilize over time. This is because of the negative exponential nature of the decay function. By harvesting these residues and transporting them to a power plant, we avoid the decay-related carbon emissions. These avoided carbon emissions grow over time. However, the avoided carbon emissions over time are growing at a slower rate than the cumulative electricity that can be generated by harvesting them. Again, this is mostly because of the negative exponential nature of the decay function. As a result, the avoided emissions per unit of generated electricity declines over time. If the emissions incurred during the harvesting, collection and transporting of these harvesting residues are lower than the avoided carbon emissions by removing them from the forest, then there is a net saving in carbon emissions to the atmosphere. We compare this net carbon emission intensity of electricity generated from harvesting residues to that of natural gas, which is estimated to be 81.67 grams of C per unit of electricity generated.

Results

Every 25 years when forest resources are harvested and harvesting residues are generated on one hectare of land, emissions generated during the process of harvesting, chipping, and transporting harvesting residues to the power plant are estimated to be 4.54 grams of C per unit of electricity generated (Table 3). This implies that the majority of carbon emissions (about 62%) related to harvesting residues production and transportation are related to the second step i.e., transportation of harvesting residues only.

Table 3: Emissions related to harvesting residue processing and transportation.

	C Emissions
C Emissions (logging, skidding, and chipping)	1.73 g C/kWh
C Emissions (transportation)	2.81 g C/kWh

Figure 1 shows avoided carbon emissions per unit of electricity due to the removal of harvesting residues from a hectare of forestland. Avoided carbon emissions per hectare grow over time since cumulative residues per hectare increase over time. However they grow at a declining rate because of the negative exponential decay function. On the other hand, the cumulative electricity that can be generated by removing those residues for electricity generation each year increases linearly over time as shown in Figure 1. Thus, the savings from avoided carbon emissions per unit of electricity are largest in the first year and decline over time and then stabilize around 100th simulation year (Figure 2). The life-cycle emissions from producing harvesting residues for use in a power plant are the same each year (Figure 2).

Figure 1: Carbon emissions due to decaying harvesting residues and cumulative electricity generated by utilizing harvesting residues for electricity generation.

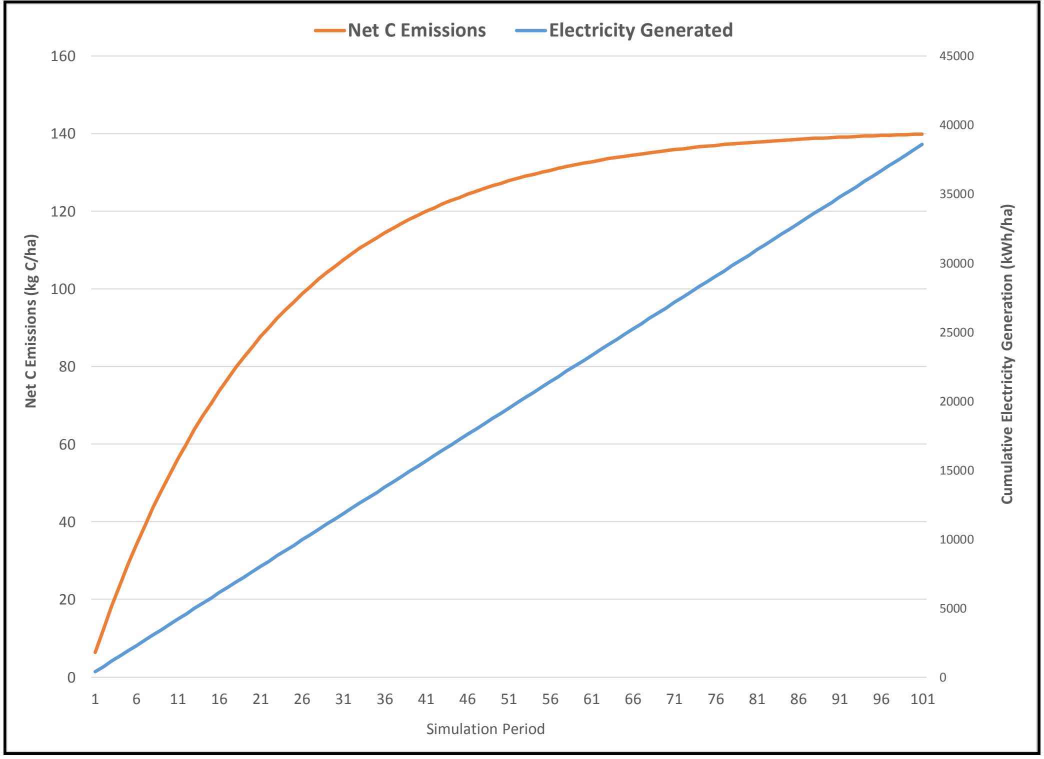
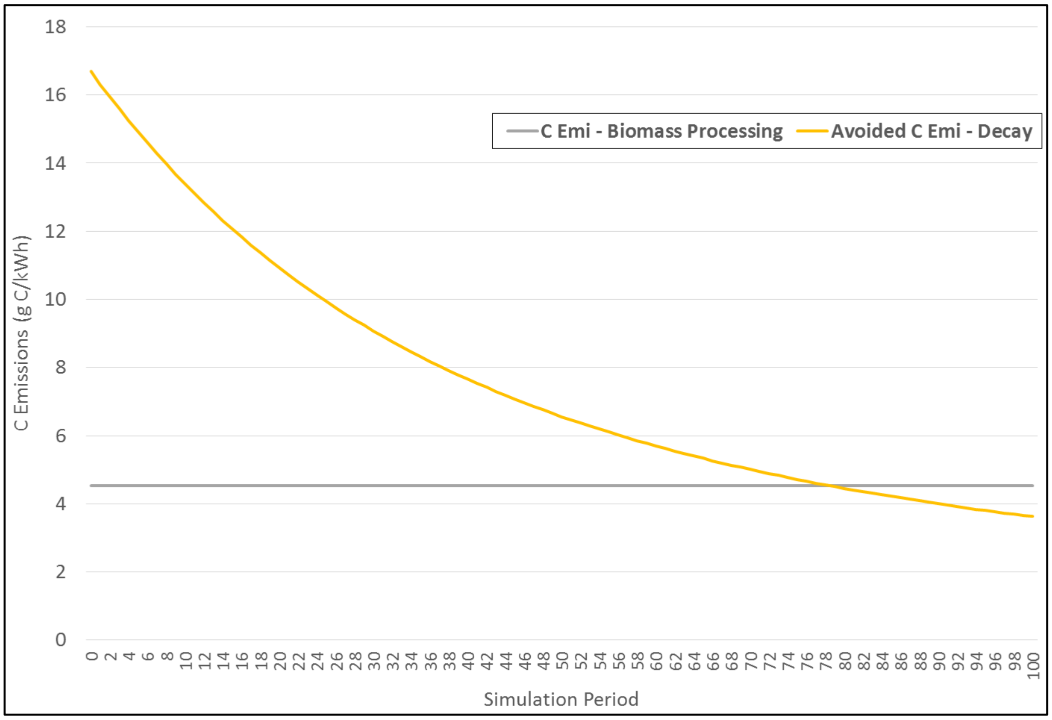


Figure 2: Carbon emissions due to biomass processing and transportation & avoided C emissions due to decay of harvesting residues.



To estimate carbon emissions per unit of electricity using harvesting residues in a manner that can be compared with that of natural gas electricity, we subtracted the avoided emissions per kilowatt hour from the life-cycle emissions due to producing and delivering harvesting residues. Since the avoided emissions tend to a very small value over time, the net carbon intensity of harvesting residue-based electricity increases over time and approaches the life-cycle emissions generated per unit of electricity from producing and delivering harvesting residues.

Figure 3 shows the net carbon intensity of the residue-based electricity. It increases over time since the benefits in terms of avoided emissions per unit of electricity by removal of residues from the forest decline over time. Figure 4 shows that the percentage savings in carbon intensity of electricity with harvesting residues relative to natural gas-based electricity with a carbon intensity of 81.6 grams of C is emitted per unit of generated electricity decreases over time. In the long run, the savings in carbon intensity of electricity with harvesting residues tends to approach about 98% of the emissions intensity of natural gas based electricity.

Figure 3: Net Carbon Intensity of Residue Based Electricity (grams of C per kWh).

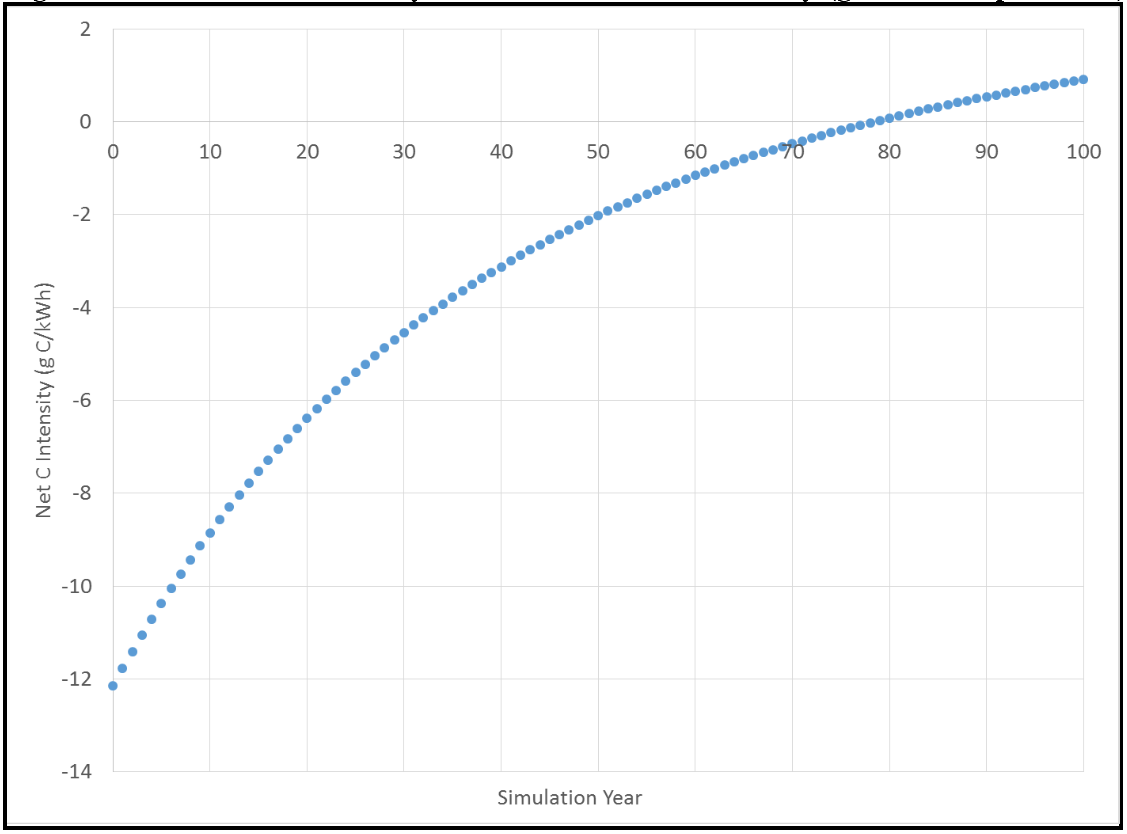
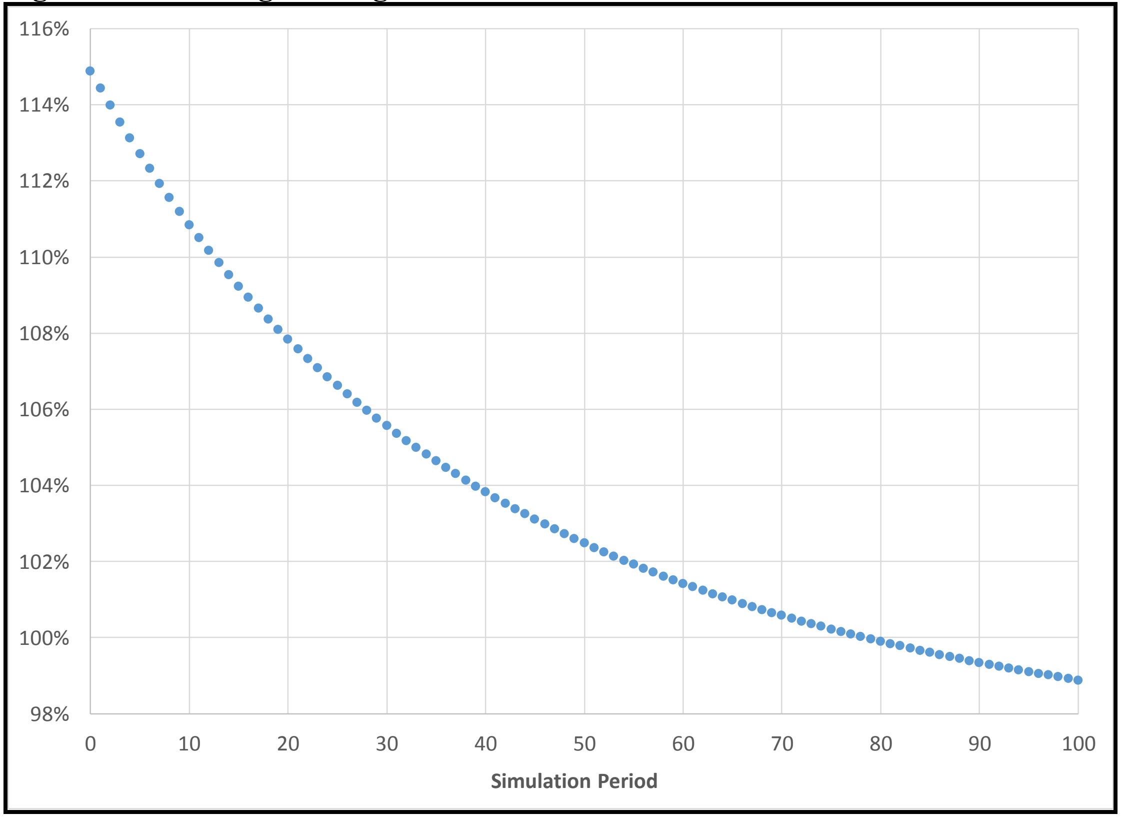


Figure 4: Percentage Savings in C Emissions Relative to Natural Gas-Based Electricity.



We examined the sensitivity of the carbon savings for the following four parameters at the stand level: percentage of methane from decaying harvesting residues[4] (0% (base scenario), 1% and 2% of original carbon emissions); decay rate (10 years, 15 years (base scenario), and 20 years); harvesting residues haul distance (64.4 km, 80.5 km (base scenario), and 96.5 km). The sensitivity analysis (Figure 5) indicates that carbon savings are most sensitive to methane emissions from decaying harvesting residues. Even a small percentage share of methane in the carbon emissions from decaying harvesting residues can significantly increase the emissions savings by using residues for electricity generation compared to natural gas. This is due to the fact that the global warming impact of methane emissions is 21 times that of same amount of emissions in the form of carbon dioxide. Percentage carbon savings were robust to the assumption of yield of harvesting residues per hectare.

Conclusion

Our assessment of the carbon intensity of harvesting residues used for generating electricity using the parameters described above for a 50 MW generating Unit and a landscape level perspective indicate that the use of harvesting residues to displace natural gas based electricity can result in savings ranging from 115% in initial years of commencing harvesting of those residues to about 98% by year 100.

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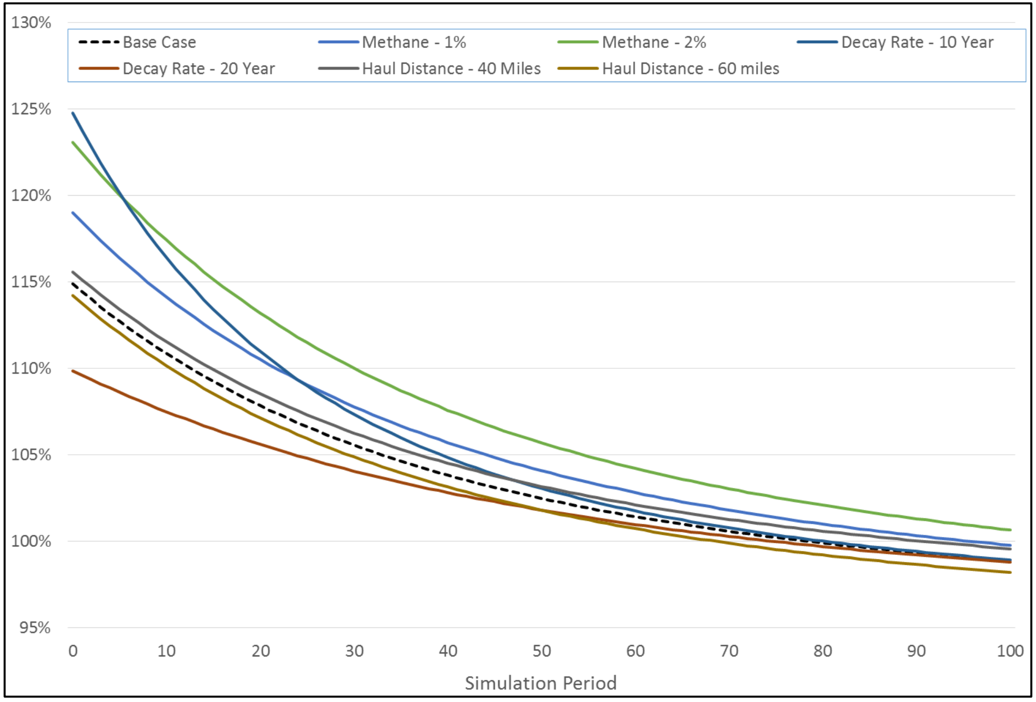
[4] At 0%, all the emissions from decaying harvesting residues are in the form of carbon dioxide. In the 1% (and 2%) scenario, 1% (or 2%) of all emissions are in the form of methane and remaining 99% (or 98%) are in the form of carbon dioxide.

Thus, the use of residues for electricity generation is carbon negative in the early years and its carbon intensity is close to zero by year 100. A landscape level perspective is consistent with commercial forest management practices that generate a continuous supply of biomass for a power plant. Our base case analysis assumed no methane emissions from the decay of harvesting residues left in the forest. Even a modest assumption that 1% of the carbon emissions generated are in the form of methane can substantially increase the near term benefits of removing harvesting residues and using them for electricity generation instead of leaving them in the forest and continuing to burn natural gas for electricity.

Figure 5: Sensitivity of percentage savings in Carbon intensity of harvesting residue-based electricity relative to natural gas based electricity to selected parameters.



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