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## Drones for Commercial Last-Mile Deliveries: A Discussion of Logistical, Environmental, and Economic Trade-Offs

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# Drones for commercial last-mile deliveries: a discussion of logistical, environmental, and economic trade-offs

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Seminar – University of Toronto

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# Drones for commercial last-mile deliveries: a discussion of logistical, environmental, and economic trade-offs

3 papers in one presentation

No formulae in this presentation

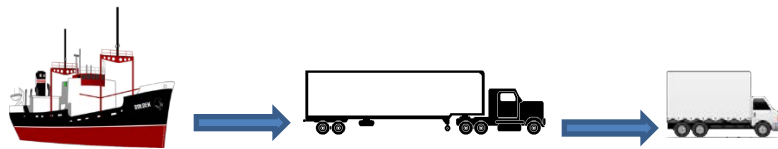
# Urban Delivery Industry Landscape

- Congestion
- Pollution – air, water, and noise
- Scarcity of parking in urban areas
- Pressure to meet environmental mandates
- Rapid increase in package deliveries and service calls
- Urban population growth
- Growing problems – growing market (online, real-time)

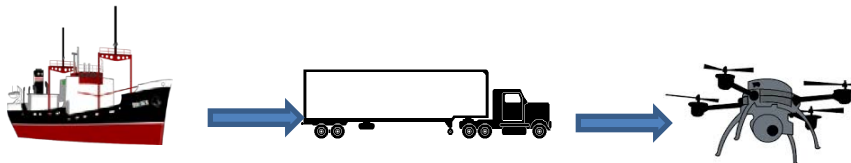


# “reinventing” the last-mile

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Conventional supply chain with truck last-mile deliveries



“New” supply chain with drone last-mile deliveries

# Survey of UAV capabilities

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- Methodology: extensive internet search
- Information on websites along and downloadable material
- In some cases, customer service was contacted to request additional information.
- Smaller drones: not designed to carry packages (weight of cameras, etc. is a proxy for payload)
- **21 UAVs** currently available in the market.

# Survey of UAV capabilities

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- Inclusion of multicopter UAVs that cover the range of existing capabilities, sizes and prices.
- Search limited to multicopter drones that can potentially deliver in both urban and rural areas.
- No helicopters (1 propeller) due to safety reasons
- No fixed wing drones due to lack of VTOL
- Electric due to noise and environmental reasons (more later)

# Photo sources: microdrones and DHL





# Speed, Flying Times, Ranges and Payloads

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- Speeds: Most speeds are in the range of 16 to 20 meters per second (35 to 45 miles per hour)
- Flying times: 20 to 30 minutes.
- Ranges: heavily dependent on a multitude of factors (payload size, weather, flown within LOS etc.).  
Typical range 15 - 35 kms (~ 10 - 22 miles).
- Payloads: affect range, depending on configuration, typical 6.4 kg to 1.8 kg. (14 to 4 lbs).

# Size and Weight

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- Typical payload/takeoff-weight ratio ranges from 0.33 to 0.20; battery/takeoff-weight ratio typically ranges from 0.30 to 0.25.
- Average size across the diagonal is 1,045 mm, typical range 1485 to 350 mm (w.o. propellers)
- The typical takeoff weight is approximately 4 kg longer-range drones have a takeoff weight of 10 kg or more.

# Costs

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- Wide range of costs:
  - Small multicopters cost a few hundred dollars.
  - The most expensive multicopters cost over \$20,000 each.
- The wide range is explained by the different capabilities and the cost of the batteries.

# Typical UAV and delivery van

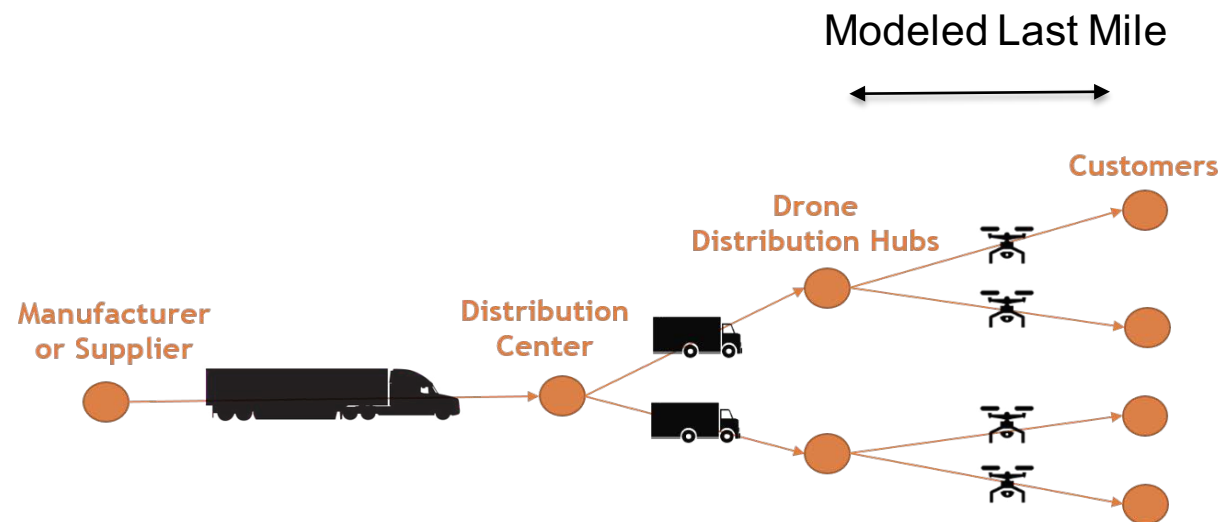


	<b>UAV</b>	<b>Diesel cargo van</b>
<b>Specification</b>	<b>MD4-3000</b>	<b>RAM ProMaster 2500</b>
Take off / Gross weight	15.1 kg	4060 kg
Tare / Curb Weight	10.1 kg	2170 kg
Max. Payload	5.0 kg	1890 kg
Max. Range	36 km	695 km

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# Drones for commercial last-mile deliveries: a discussion of economic, logistical, and environmental trade-offs

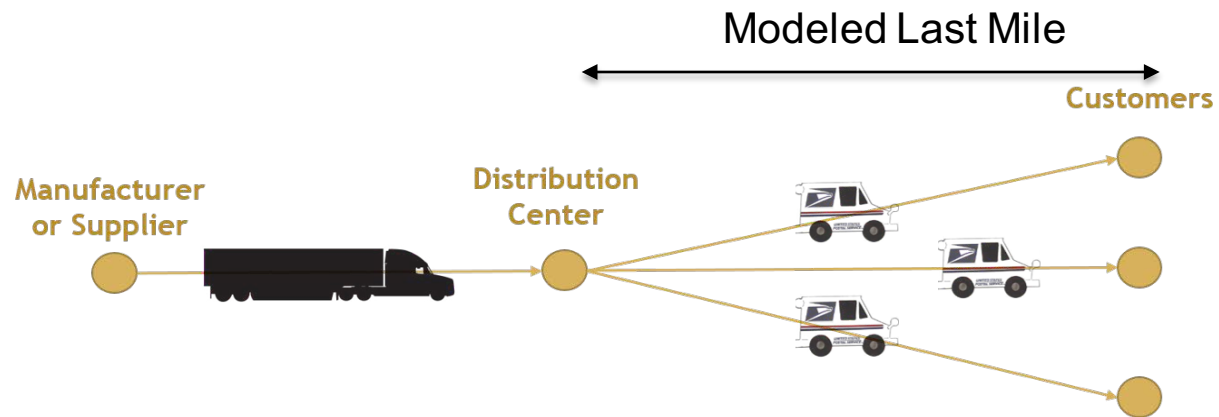
# One-to-one last-mile routes



One vehicle serves 1 (one) customer per round trip

# One-to-one last-mile routes

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One vehicle serves 1 (one) customer per round trip

# Typical UAV and delivery van



	<b>UAV</b>	<b>Diesel cargo van</b>
<b>Specification</b>	<b>MD4-3000</b>	<b>RAM ProMaster 2500</b>
Range	25 km (practical)	695 km
Battery/Fuel Capacity	0.777 kWh	8.63 kWh
Energy consumption	21.6 wh/km	1016 wh/km

**Per-unit distance the UAV is almost 50 times more energy efficient than the van assuming a 5kg payload**  
 Why ? Physics !



# Typical UAV and delivery van

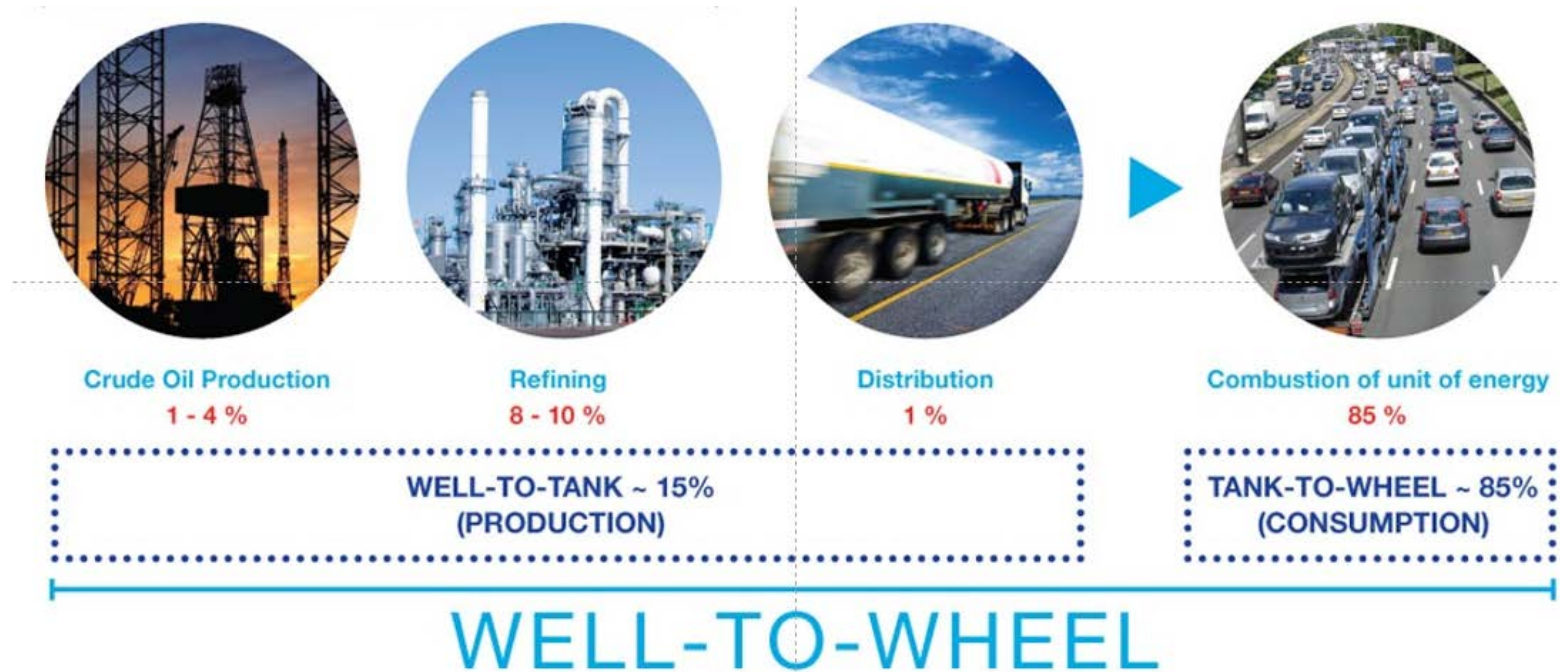
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Per-unit distance the UAV is 50 times more energy efficient than the van (assuming a 5kg payload), but...

The van can deliver almost 400 times more cargo than the UAV; **assuming maximum payloads the van is almost 8 times more energy efficient**

# Well-to-tank (WTT) and Tank-to-wheel (TTW) Fuel CO<sub>2</sub>e emissions



Source: White Paper on Fueling EU Transport, EUROPIA, 2011

# Typical UAV and delivery van

Per-unit distance the UAV is 1050 times cleaner than the van (assuming a 5kg payload)



	<b>UAV</b>	<b>Diesel cargo van</b>
<b>Specification</b>	<b>DJI S1000</b>	<b>RAM ProMaster 2500</b>
Range	25 km	695 km
Battery/Fuel Capacity	0.777 kWh	8.63 kWh
WTT emissions	1.235 lbs CO <sub>2</sub> e / kWh	5.108 lbs CO <sub>2</sub> e / gallon
TTW emissions	-	22.72 lbs CO <sub>2</sub> e / gallon
Energy consumption	10.8 wh/km	1016 wh/km

WTT = well to tank    TTW = tank to wheel

# Typical UAV and delivery van

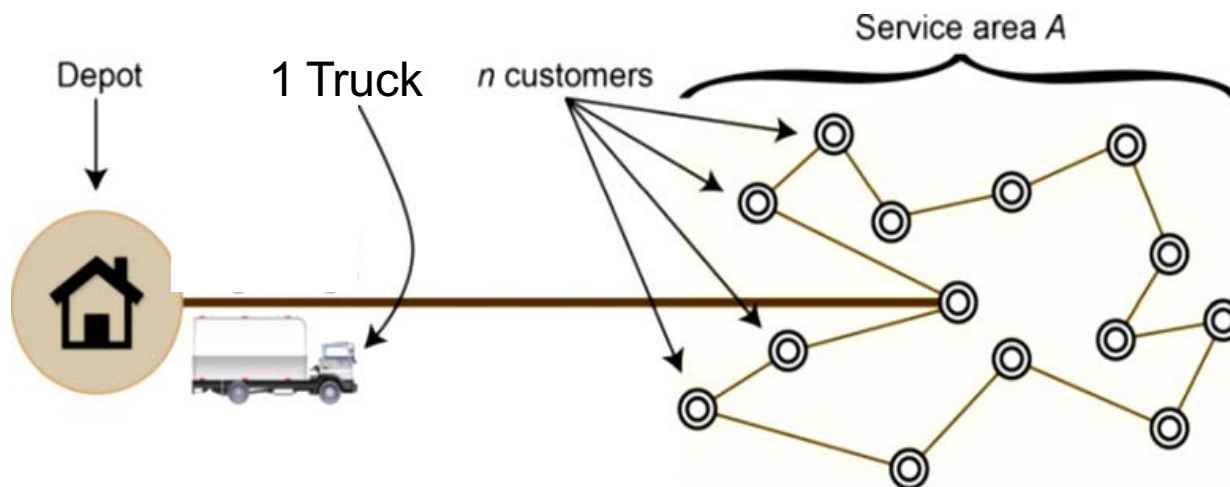
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Per-unit distance the UAV is 1050 times cleaner than the van (assuming a 5kg payload), but...

The van can deliver almost 400 times more cargo than the UAV; **assuming maximum payloads** the van is 8 times more efficient in terms of energy consumption but **the van is almost 2.8 times less efficient regarding CO<sub>2</sub> emissions.**

# One-to-many last-mile routes



**One** vehicle serves  $n$  (**many**) customers

More efficient as  $n$  grows (distance traveled by customer)

UAV carry just one package at the time

# Energy efficiency breakeven points



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**TABLE 3. UAV and Diesel Van Breakeven Energy Scenarios - One-to-one Routes**

Avg. Dist. depot to Customers (km)	Service Area (km <sup>2</sup> )	<i>n</i> *		
		$\rho_1^{en} \sim 94$ 10.8 wh/km	$\rho_1^{en} \sim 47$ 21.6 wh/km	$\rho_1^{en} \sim 31$ 32.4 wh/km
8	60	1,340	362	173
9	40	785	224	113
10	20	413	131	72
11	7	219	83	50
12	1	127	58	37

**Reference point:** how many packages are delivered by a typical UPS vehicle ?  
(urban areas)

# Energy/emissions efficiency breakeven points



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Electric Van

Avg. Dist. depot to Customers (km)	Service Area (km <sup>2</sup> )	$n^*$ $\rho_1^{en} \sim 35$ vs. E-truck	$n^*$ $\rho_1^{en} \sim 9.5$ vs. E-van
8	60	214	26
9	40	137	20
10	20	85	15
11	7	58	12
12	1	42	10

**Reference point:** how many packages are delivered by an electric van/truck?

# Energy/emissions efficiency breakeven points



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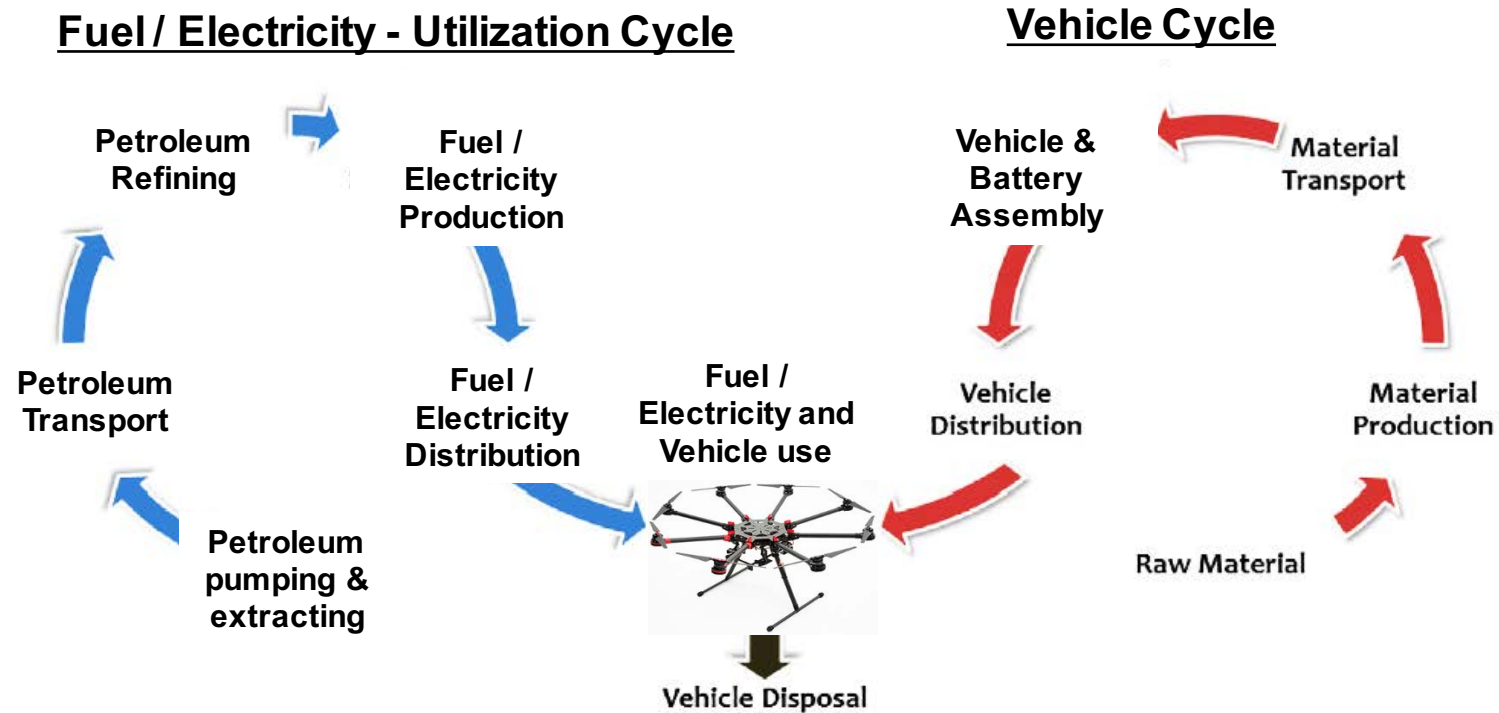
Avg. Dist. depot to Customers (km)	Service Area (km <sup>2</sup> )	$n^*$ $\rho_1^{en} \sim 1.4$ vs. E-tricycle
8	60	2.1
9	40	1.9
10	20	1.7
11	7	1.6
12	1	1.5

**Reference point:** how many packages are delivered by a typical tricycle?



# Lifecycle: add production, maintenance and disposal

(also includes maintenance and spare parts)



Source: adapted from M. Shahraneeni et al.

# Lifecycle assessment

**TABLE 7. Per Delivery Vehicle Phase CO<sub>2</sub>e Emissions (\*\*)**

Parameter	UAV	Tricycle	Diesel Van
Number of daily deliveries	4	25	150
Delivery days per year (days)	260	260	260
Vehicle life (years)	3	5	10
Emissions per delivery (kg CO <sub>2</sub> e per delivery)	0.16	0.02	0.03
Equivalent travel distance (in km) (kg CO <sub>2</sub> e per delivery)	13.0	1.2	0.002
Range (km)	25	48	625
Equivalent travel distance as % of range	52	2.5	0.0

(\*) Included in the vehicle chassis (\*\*) To improve readability numbers have been rounded

# Economics

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- Vehicle costs
- Battery costs
- Labor costs
  
- Energy costs
  
- Other costs (overhead, fixed costs)

# Many potential scenarios

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- Impact of regulation, BLOS operation?
- Utilization ? Useful life?
- Weight of energy costs
- Key cost elements

# Key logistical tradeoffs

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- Speed and reliable (uncongested airways?)
- Low payloads and limited range
- For high payloads (more than 7 kgs) or long distances ground vehicles are still dominant
- Drop-off technology/solutions? Multiple?

# Key environmental tradeoffs

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- Relatively low per-mile emissions
- Relatively high vehicle phase emissions
- UAVs very CO<sub>2</sub>e efficient (per-unit distance)
- EVs and Tricycles more CO<sub>2</sub>e efficient with multiple dropoffs

# Key economical tradeoffs

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- High cost per delivery when compared to traditional parcel deliveries
- Dynamic and uncertain cost variables
- New markets and opportunities?

# Other key issues

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- Air traffic control
- Safety, liability and litigations
- Energy (clean electric vs. carbon based)
- Regulation and land use restrictions
  - Noise
  - Privacy
- Technology: batteries, electronics, ...



# Related Publications

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- Figliozzi M., Lifecycle Modeling and Assessment of Unmanned Aerial Vehicles (Drones) CO<sub>2</sub>e Emissions, forthcoming 2017 Transportation Research Part D
- Figliozzi and Tucker, What can multicopter drones deliver? A survey and analysis of the capabilities and limitations of state of the art drones, Submitted to TRB 2018
- Figliozzi M., Economic and Market Analysis of multicopter drones deliveries, Working paper.

# Acknowledgements

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# THANK YOU

## Questions? Comments...

Visit the TTP Lab webpage:

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