Arjo van der Ham - CTO

How to halve the energy consumption of Electric Vehicles

Lightyear

World Champions solar car racers

Lightyear

- Bridgestone World Solar Challenge in Australia. 1877 miles across the outback.
- 40+ Teams, including MIT, Stanford, Berkeley.
- **Solar Team Eindhoven has won all four editions of the cruiser class so far.**

What makes Lightyear different?

Radical focus on improving efficiency from systems level to every component

Why is adoption slow?

Current concerns of customers:

48%	High purchase price
47%	Limited range on single charge
48%	Battery life
48%	Limited access to plug-in stations
38%	Lengthy charge times

Percentages of consumers with specified concern — IHS Markit, AlixPartners analysis

Range vs price:
Affordable car with large range

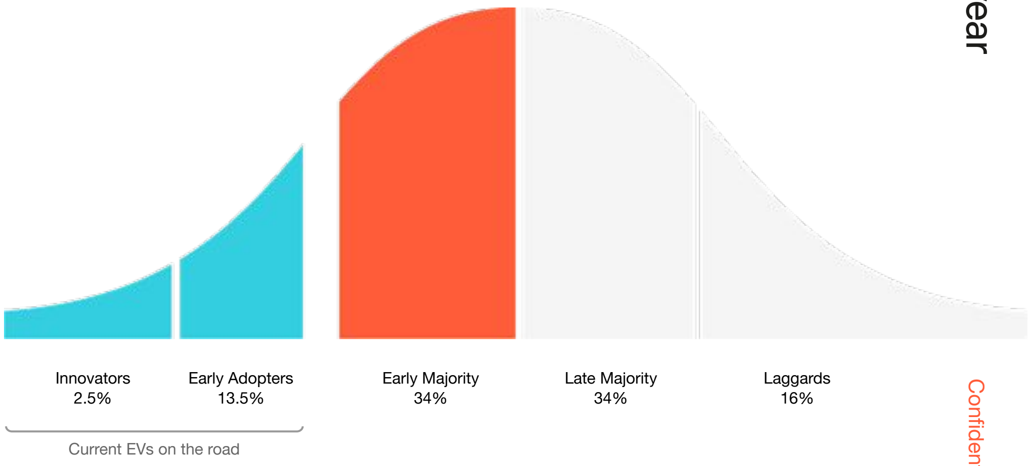
Charging: Can I drive my EV day in, day out?

Why we exist

Early majority expects EV's to be as capable as ICE

- "I want to do all of my business driving without delays"
- "I always want my AC and heating"
- "I want drive fast for long periods of time if needed"
- "Go on a weekend trip without charging worries"
- "One day business trip without charging stops"

Btw… I don't want to pay a premium over my ICE car.



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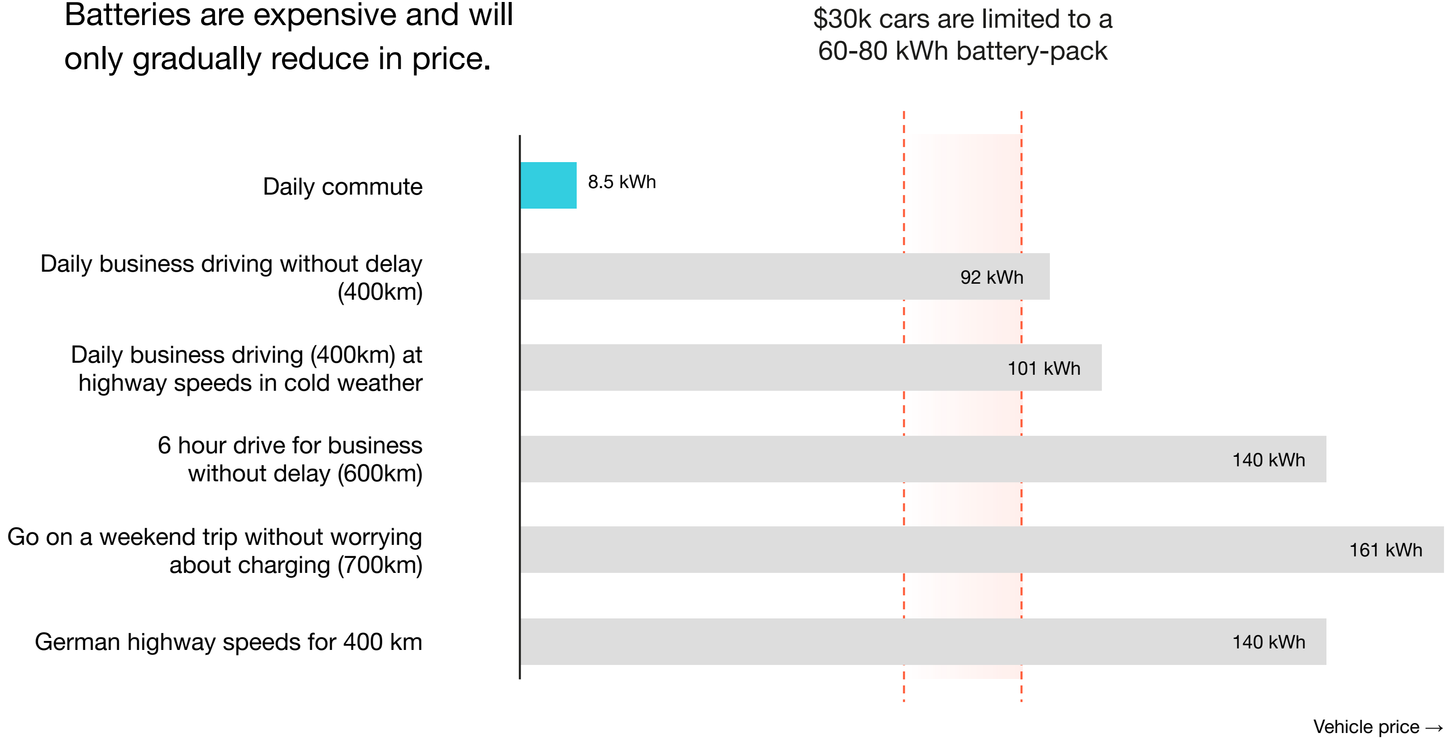
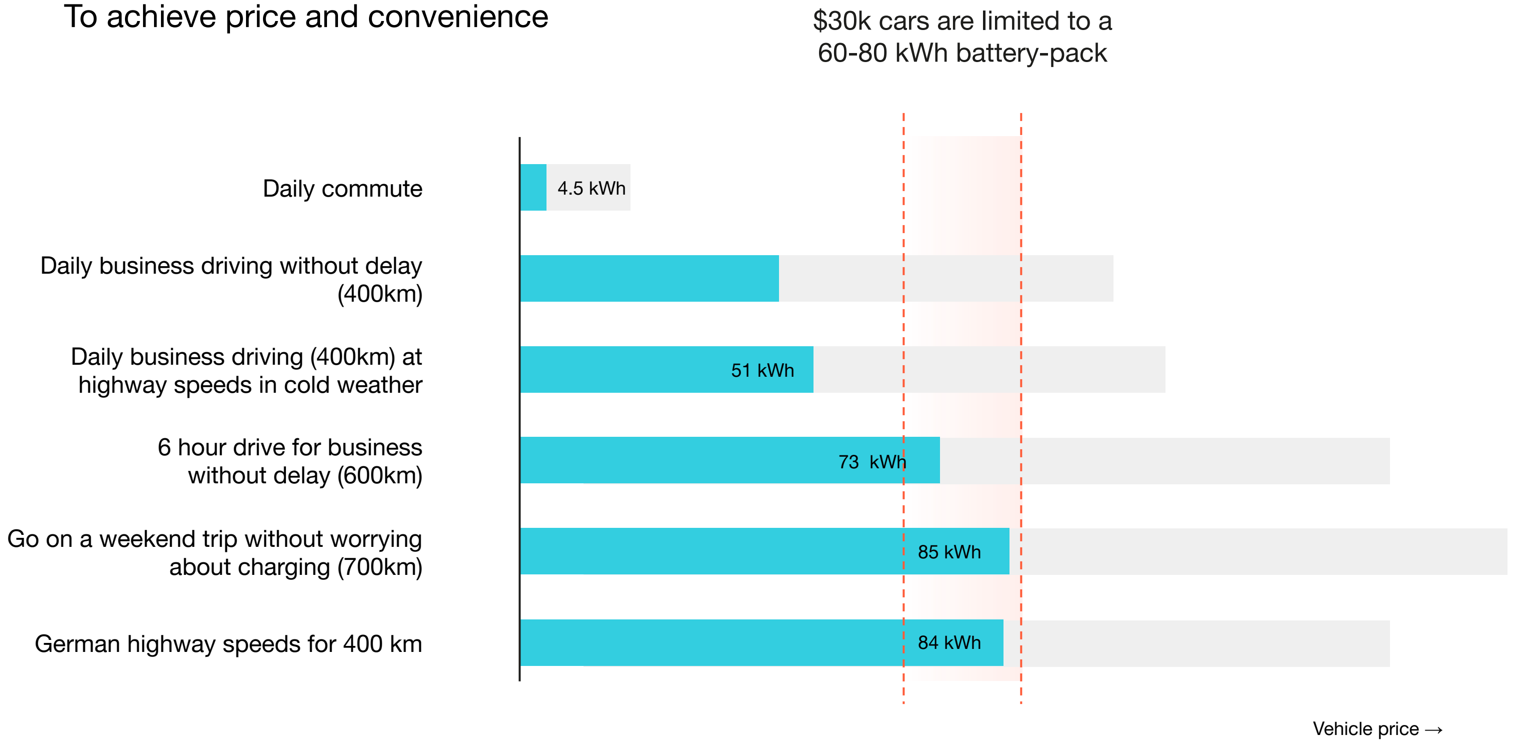
It’s all about energy

Batteries are expensive and will only gradually reduce in price.



Efficiency is the only way

To achieve price and convenience



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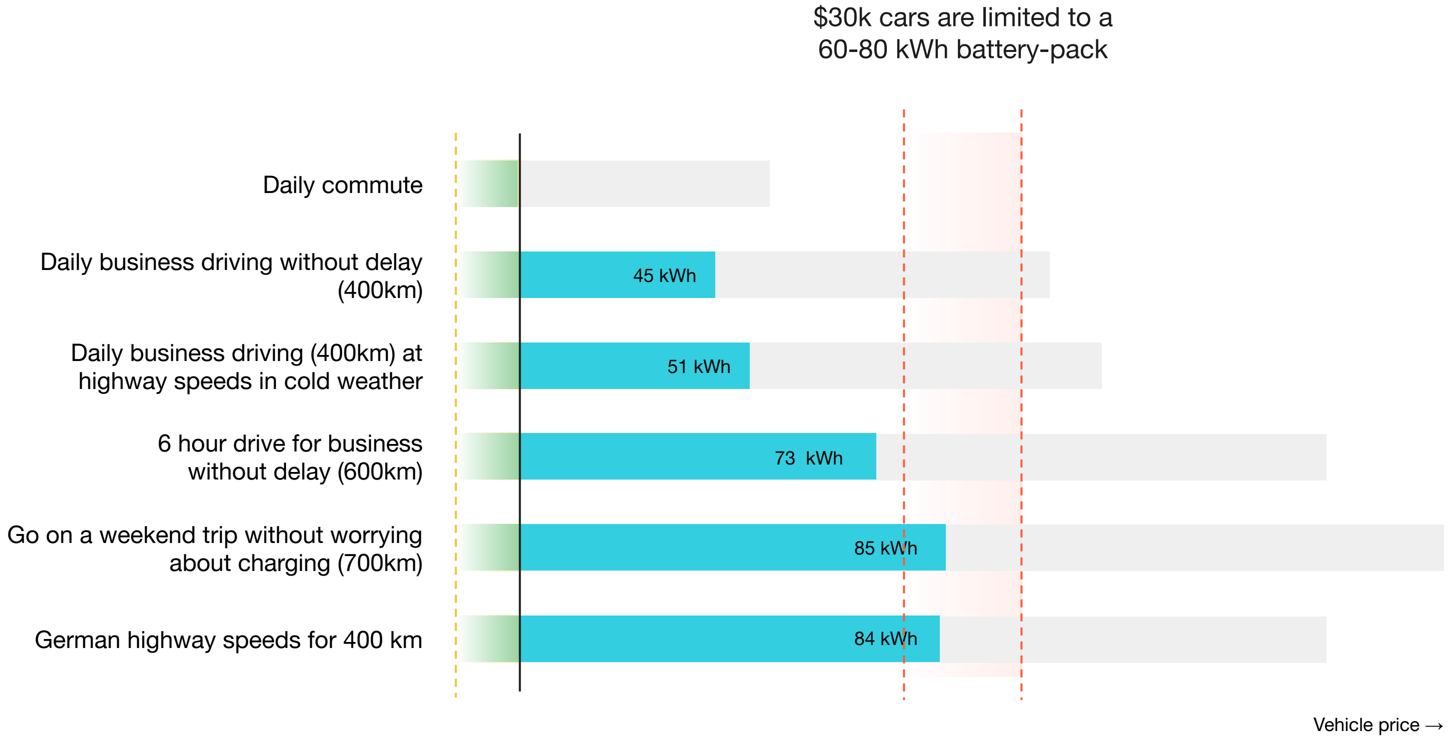
Integrated solar is magical convenience improver



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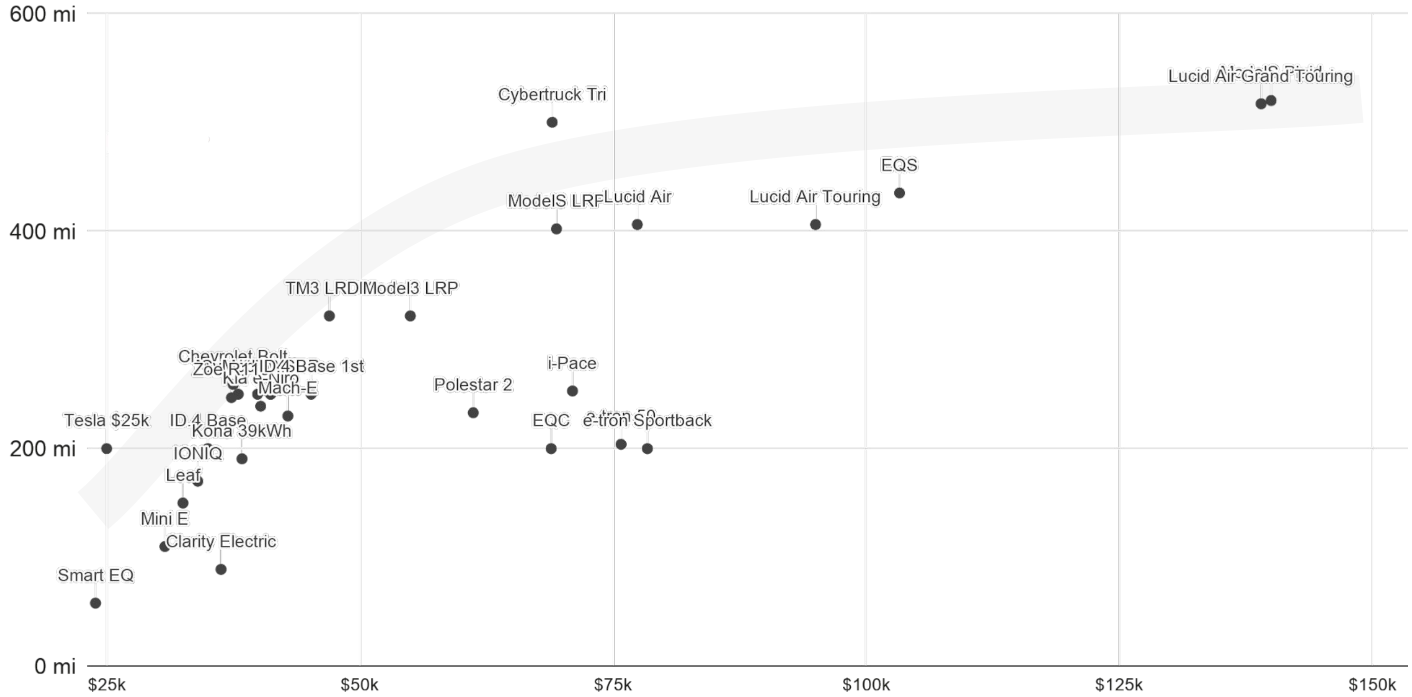
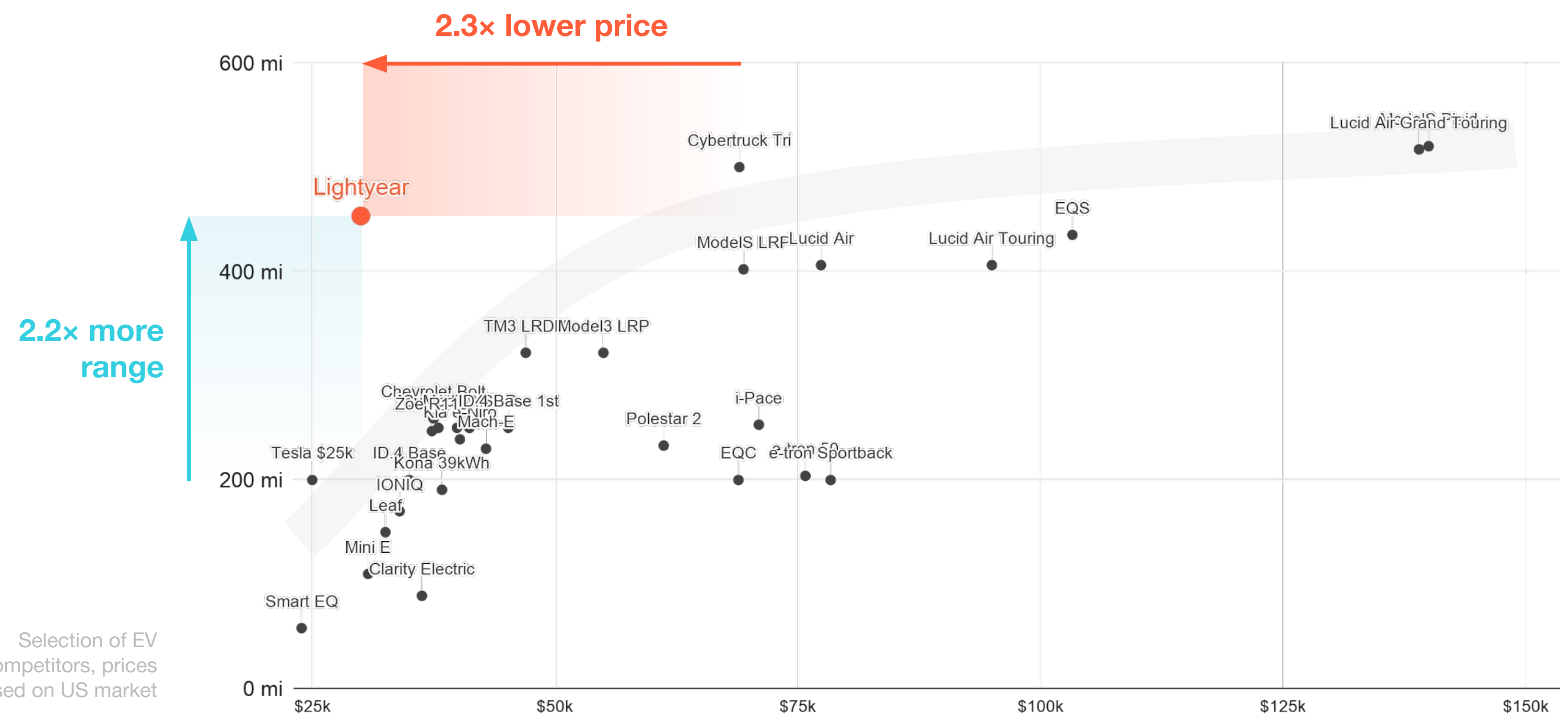
Other OEMs fail to break the trend



Selection of EV competitors, prices based on US market

We found a way to break it



Selection of EV competitors, prices based on US market

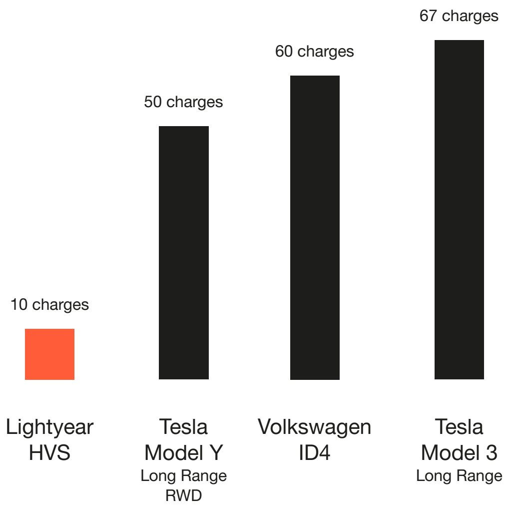
60% of Londoners can't install a home-charger

5×

Less charge hassle then closest competitor during commute

50—74%

Of commute on the sun (Netherlands — USA)



Example for an average American without an home-charger.
Commuting 22.005 miles annually in Palo Alto.

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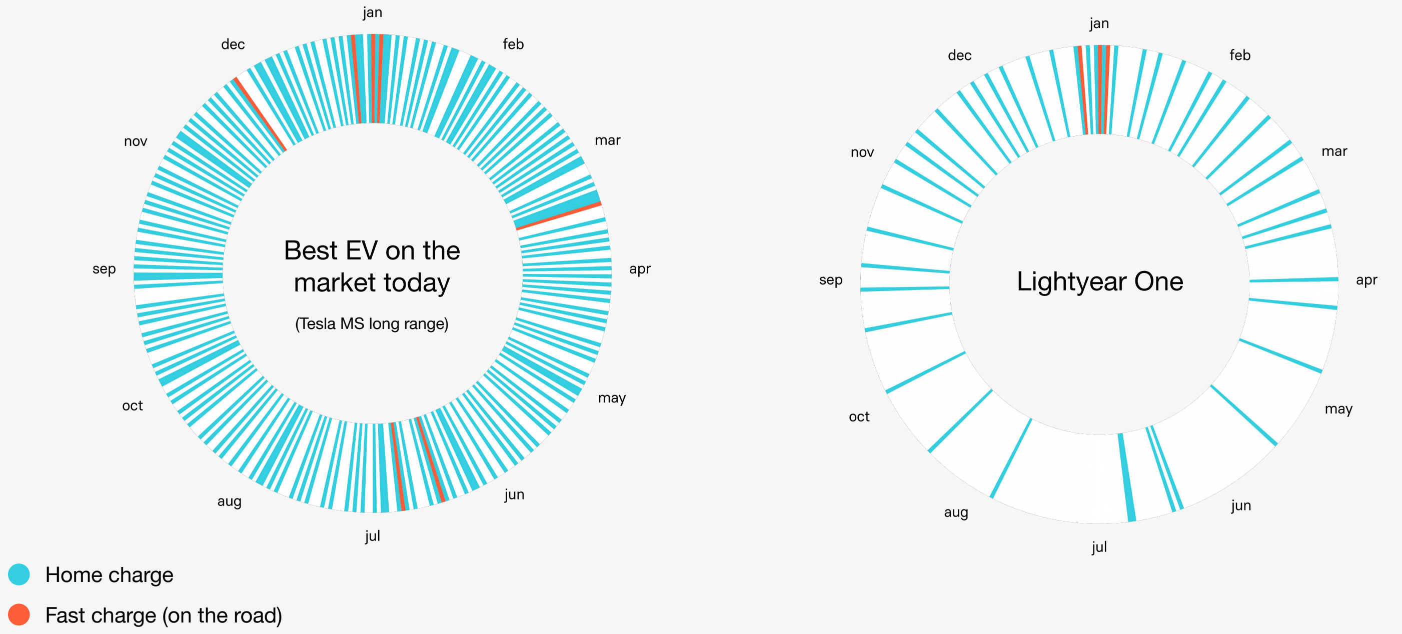
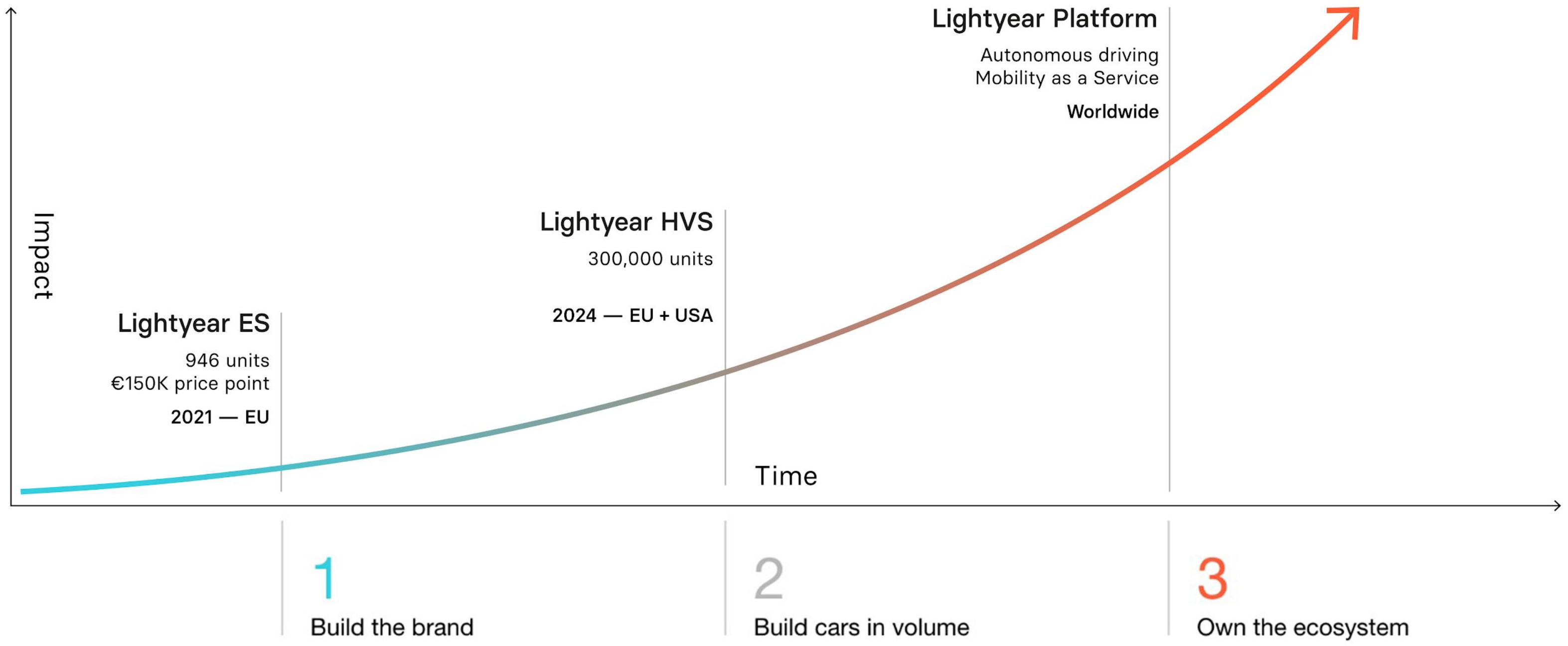
Never a question about charging anymore

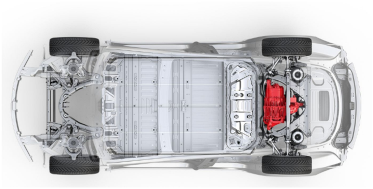
John parks his car outside at work, just like 80% of the Americans do.

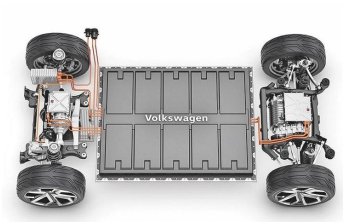


Summarizing — our overall strategy



Platforms haven’t changed for 10 years





Baseline Scenario: Target Car 20181205

Car:	ear One 60 - Tarç	
Mass (empty)	1250	[kg]
Rolling Resistance	0.0085	[-]
Cd	0.182	[-]
Frontal Area	2.202	[m2]
Wheel Radius	0.3335	[m]
# Motors	4	[-]
Motor Power Continous	10	[kW]
Motor Power Peak	20	[kW]
Motor Torque Continous	200	[Nm]
Motor Torque Peak	482.5	[Nm]
Power Train Efficiency	90	[%]
Battery Size	60	[kWh]
Solar Panel Area	5.05	[m2]
Cell Efficiency	22	[%]
Conversion Efficiency	95	[%]
Auxiliary Power	250	[W]
HVAC Power	850	[W]
Inertia (% of vehicle mass)	3	[%]

Settings		
Standard Slope	0	[%]
Steep Slope	47.5	[%]
Gravitational constant	9.81	[m/s2]
Air Density	1.225	[kg/m3]
Annual Solar irradiance	1000	[kWh/m2/year]
Shadow Correction	0.7	[-]
Drive Cycle	WLTP	
Passenger Weight	75	[kg]
Nr. Of passengers	1.3	[-]

Results			
Top Speed			
	Standard Slope	**186.6**	[km/h]
	Steep Slope	**Too Steep!**	[km/h]
	Steep Slope (peak)	**12.4**	[km/h]
Acceleration			
	0 - 100	**8.8**	[s]
	peak on standard slope	**4.09**	[m/s2]
	peak on steep slope	**0.00**	[m/s2]
Energy Usage		**105.5**	[Wh/km]
Range		**569**	[km]
Annual Solar Kms		**7004**	[km/year]
Daily Solar Kms		**19**	[km/day]

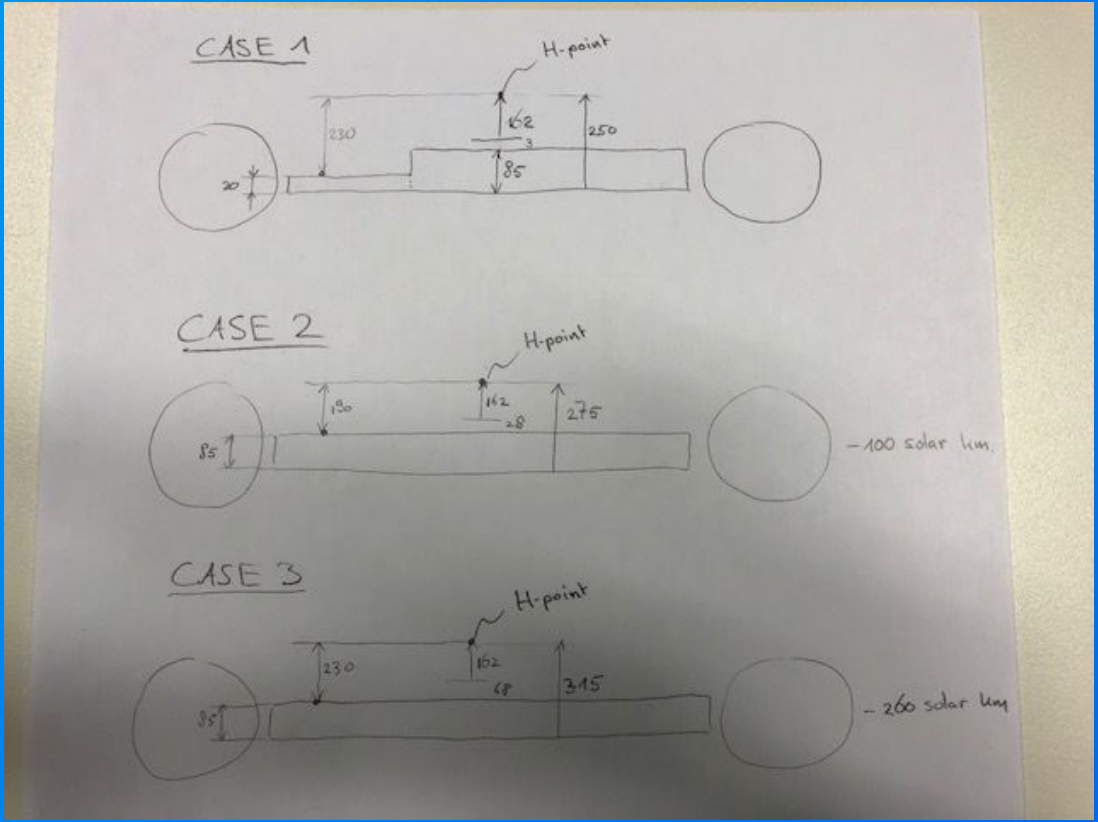
L I G H T Y E A R

3 battery packaging concepts

Case 1:
Dip in battery floor for front passenger feet (current design).

Case 2: **(-100 solar km)**
Completely flat battery floor with a similar seat height as a Porsche Boxter.

Case 3: **(-260 solar km)**
Completely flat battery floor with the same seat height as case 1 (230 mm)

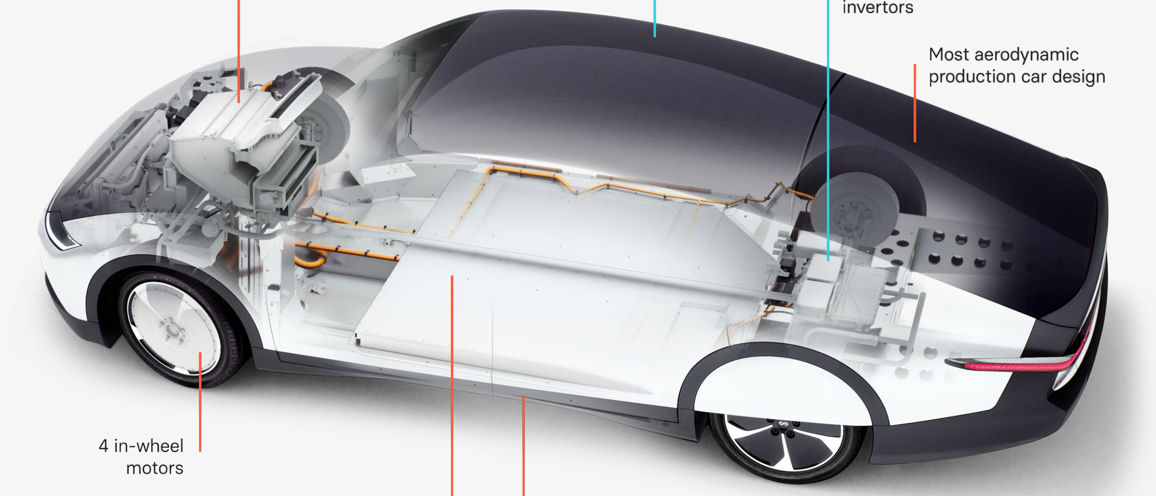


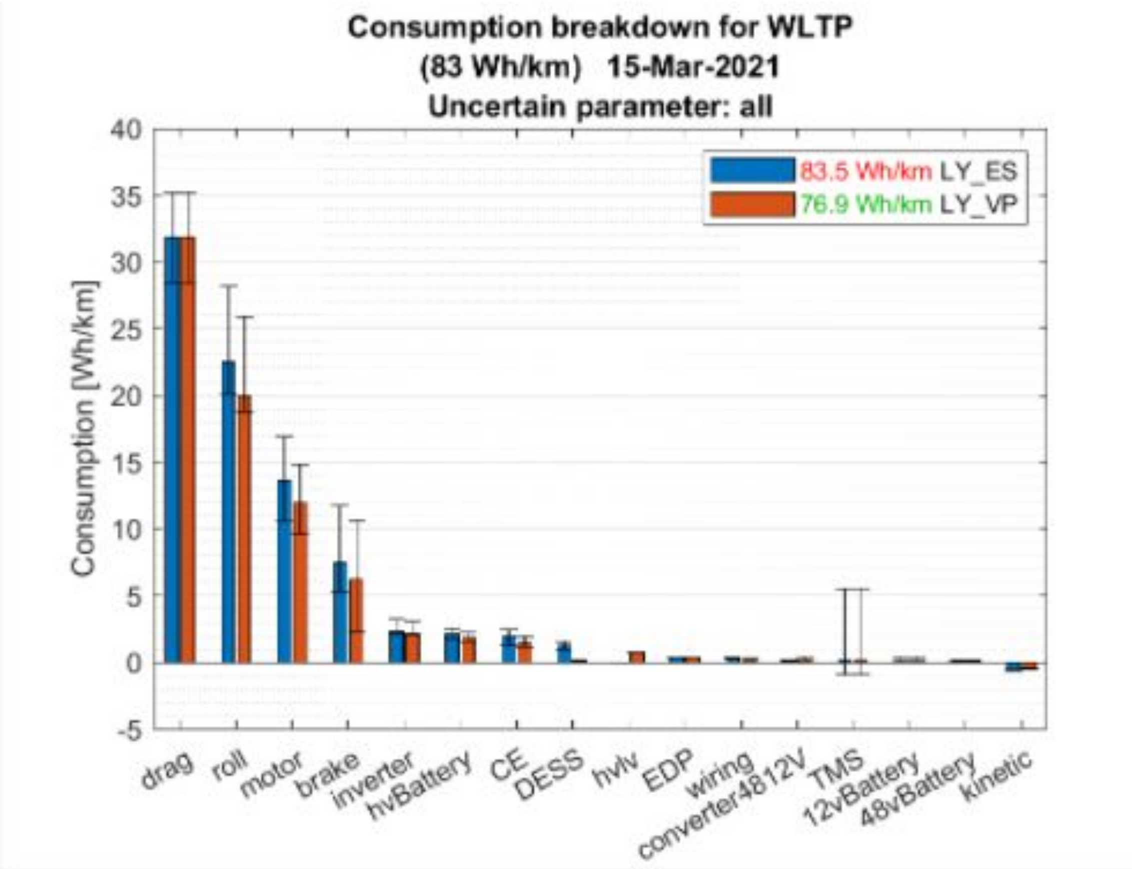
Top 3 tire options

*BMW i3 tire has no ‘all-road’ option in the same size available
*BMW i3 tire is available in different widths (i.e. 155, 175 & 195 mm) which provides more options to compensate for the weight distribution.

	OD	RRC	weight	Solar RRC	Solar mass	Solar aero	Solar total
205/55 R16 91H T001	634 mm	5.8 kg/T	6.9 kg	-	-	-	-
BMW i3 (155)	700 mm	6.7 kg/T	7 kg	-300	-1.6	+400 / +800	+98 / +498
195/55 R20 95H XL PCY3	~700 mm	6.2 kg/T	? kg	-133	?	+135	- XX

Vertical integration of key components for performance





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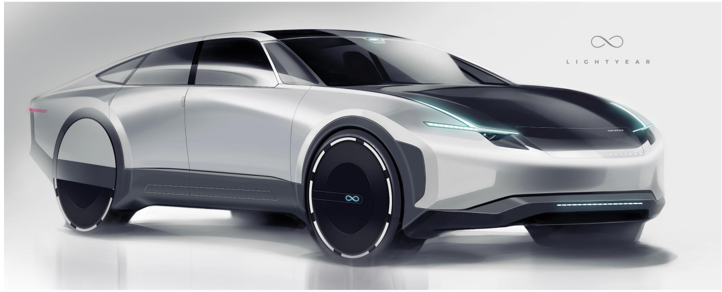
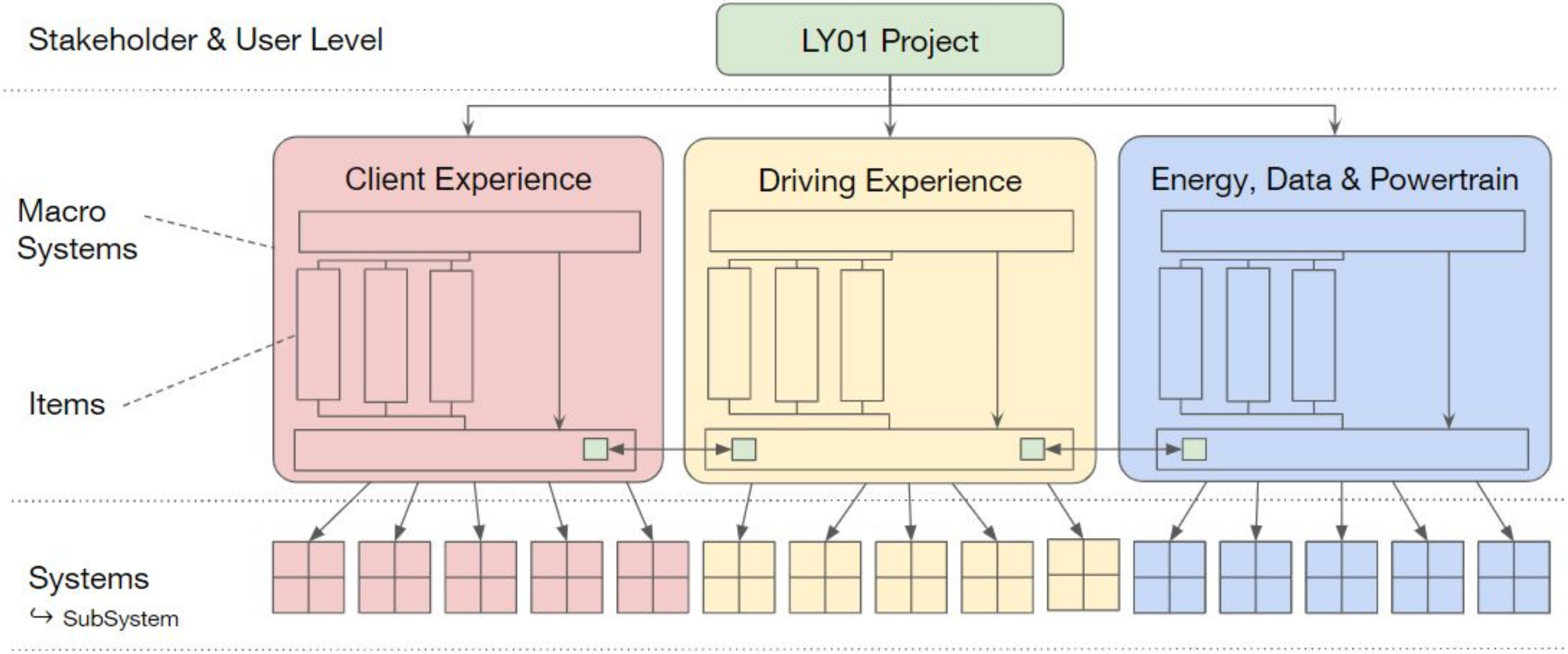
Systems Engineering





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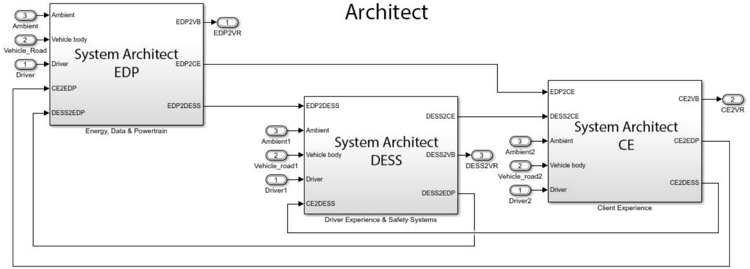
North Star Requirements View

6 items Filter Items

Project ID						Last Activity Date	# of Upstr...	# of Down...	Risk	Name
LYPD-NSREQ-3			3	1		01/04/2020	0	2	0	Charging frequency and time
LYPD-NSREQ-1			2	0		28/01/2020	0	1	0	WLTP Range
LYPD-NSREQ-2			2	0		28/01/2020	0	1	0	WLTP energy consumption
LYPD-NSREQ-4			2	0		28/01/2020	0	1	0	Target Highway Range
LYPD-NSREQ-5			2	0		28/01/2020	0	1	0	Minimum highway range
LYPD-NSREQ-6			2	0		28/01/2020	0	2	0	Annual solar range

Vehicle Architect



1 Wh/km ≙ 43 kg ≙ 44 W auxiliary power

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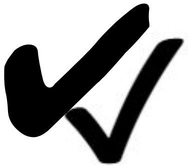
Concept Selection Matrix		Lightyear Concepts / Variants						
Revision date of template:	May 7, 2020	Variant 1			Variant 2			
Revision number of template:	2							
Decision to make:	Decision Made by:	Solar to 12V			Solar to HV			
2) Technical and functional requirements		**Fixed Requirements OK**	**Wishes:**	**77%**	**Fixed Requirements OK**	**Wishes:**	**75%**	**Fixed**
Mandatory requirements for decision		**Information about requirement**		**Fulfills?**	**Information about requirement**		**Fulfills?**	**Informatio**
Should be safe/meet ISO26262				Yes			Yes	
Wishes (negotiable)	**Weight factor (1 till 5)**	**Info**				**ore (0 till 5)**	**Weight score**	**Information ab**
Vehicle efficiency	5	VPM results + assumptions in the picture above: Similar to Solar to HV	3	15	VPM results + assumptions in the picture above: Similar to Solar to LV	4	20	Slightly better efficient
Variation on vehicle efficiency (sensitivity to usecase)	2	Not adaptable	4	8	Not adaptable	4	8	Dynamic; adap
Mass, BOM Cost, Nr of parts	3	0.3kg/DSC * 14 DSC's + 5kg/HVLV = 9.2 kg	4	12	Higher than solar to 12V: larger creepage/clearance needed; more magnetics	3	9	No HV/LV. Isola
Sensitivity to cell voltage (lower voltages allow for smaller groups/larger solar cells)	3	Prefers low voltage; can work with any voltage	5	15	Prefers higher voltage for efficiency; can work with any voltage	5	15	Only works at ~
Durability (battery cycling)	1	All power to (smaller) LV battery; will cycle more. Order of magnitude similar to cycles of HVBS. x2 for california		0	Solar power cycling insignificant		0	Solar power cy
Flexibility in packaging (wiring and position) [in contrast with integrated module arguments, therefore rated as 0, not taken into account]		Small solar converters; don't need HV. Can be placed anywhere		0	Solar conversion needs LV and HV, so needs to be placed in core of car. Single box makes most sense; but could be multiple boxes		0	Solar conversio placed in core c but could be m
Time-to-market / design complexity / FuSa	5	DSC design should be updated for 12V. Relatively easy.	4	20	New solar converters to HV needed FuSa Safety design needed for solar conversion. If not isolated; safety analysis needed on solar panels	3	15	New solar conv Isolation mand
Future proof (possibility of changing concept)	3		5	15	LV wiring needs to be added to swap with most other concepts	5	15	Solar panel vol concepts
				0			0	
				0			0	
				0			0	
				0			0	
				0			0	
				0			0	

Everybody defines their own criteria and their weights!

Model Based ~~Design~~ Optimization

Calculate the impact on the score for **every** design decision

SPEED



CONSISTENCY

Engineering as Optimization Problem

Objective Function

Describes the trade-off between cost, lifetime, range, efficiency, comfort etc.

Maximize $f(x)$

subject to $g_i(x) \leq 0 \quad i=1..m$
$h_j(x) \leq 0 \quad j=1..p$

Constraints

Defines the absolute boundaries. E.g.
- *Homologation requirements*
- *Minimum range*
- *Maximum price*

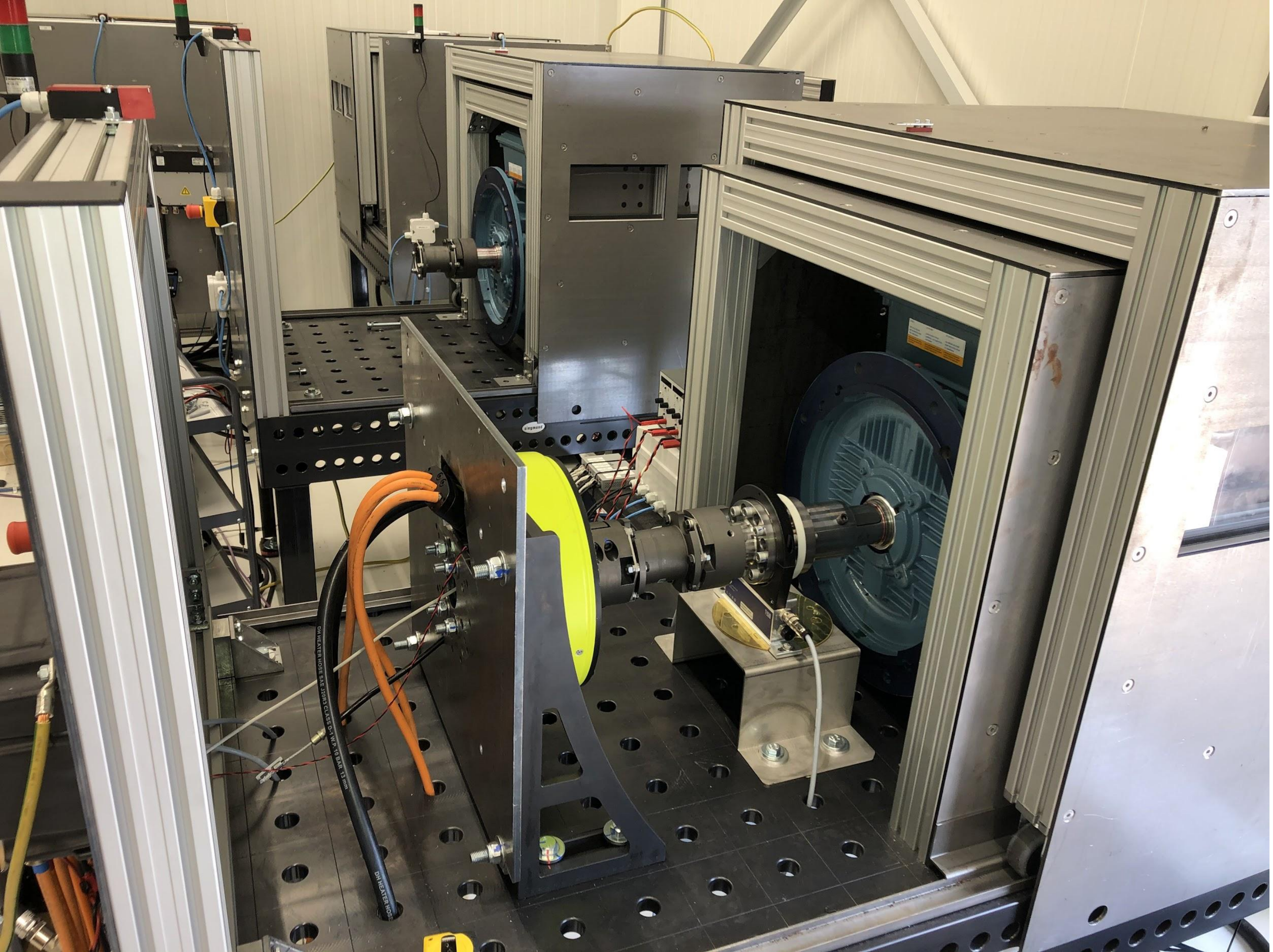
Should define a large enough solution space! Otherwise there is nothing to optimize anymore...

Lightyear High Volume Series Optimization Problem Definition

Clean Mobility for Everyone

Maximize	Potential CO_2 Savings
Subject to	Min. Sales Potential Legal Requirements

Where: Potential CO_2 Savings = f(*energy consumption, solar yield, price, desirability, lifetime*)



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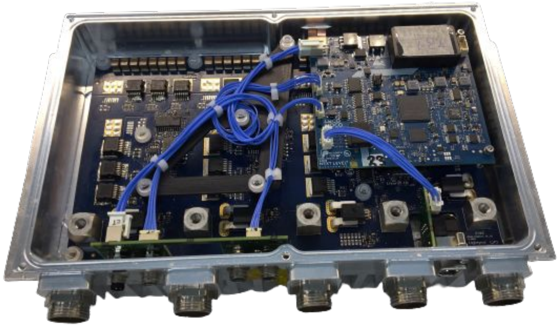
In-wheel motor technology

The world’s most efficient drivetrain

SiC Air Cooled Inverters

99.1% Efficiency over a drive cycle

20kW Peak power



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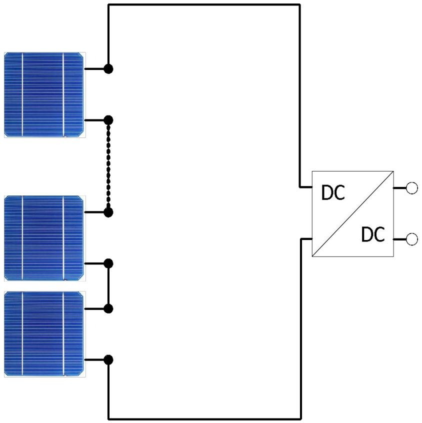
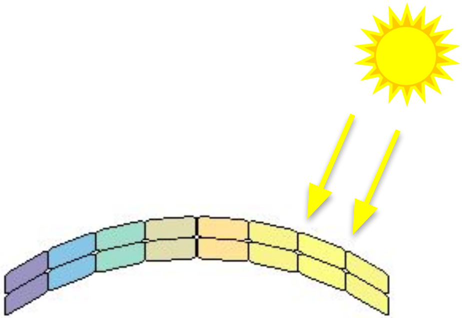
Most aerodynamic 5 seater production car in the world

Most efficient automotive grade solar panel in the world





State-of-the-art for SEV:

- 3 strings of 125 cells
- The **weakest** cell determines the string current

Curved Surfaces and **Shadows** cause mismatches between cells

Therefore, Solar Electric Vehicles have flat solar roofs

This limits **design freedom** and **aerodynamic** performance

Grouping Efficiency:
ratio between the individual cell MPPs and the suboptimal group MPPs

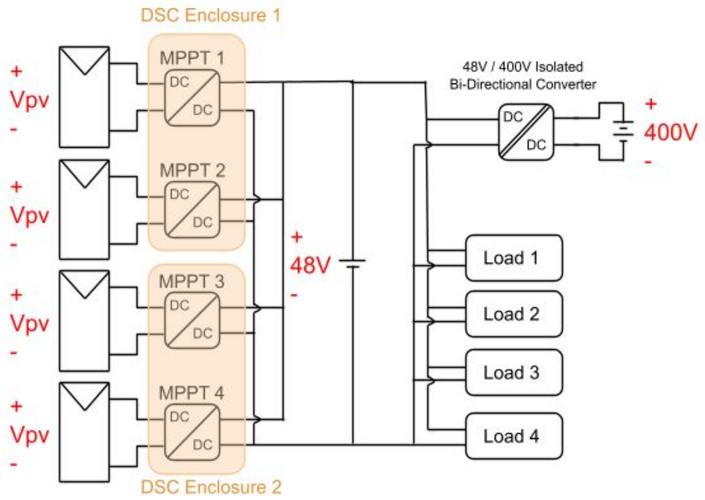
$$\eta_{group} = \frac{\sum P_{mpp,group}}{\sum P_{mpp,cell}}$$

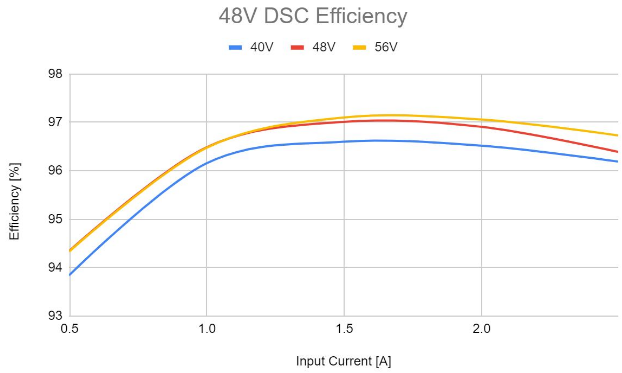
$\eta_{group} = 98.6\ \%$

$\eta_{group} = 75\ \%$

Solution: Smaller groups, AKA Distributed Maximum Power Point Tracking

Distributed Maximum Power Point Tracking





+25% Energy Yield on curved surfaces

96% Conversion Efficiency

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Thank you.

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