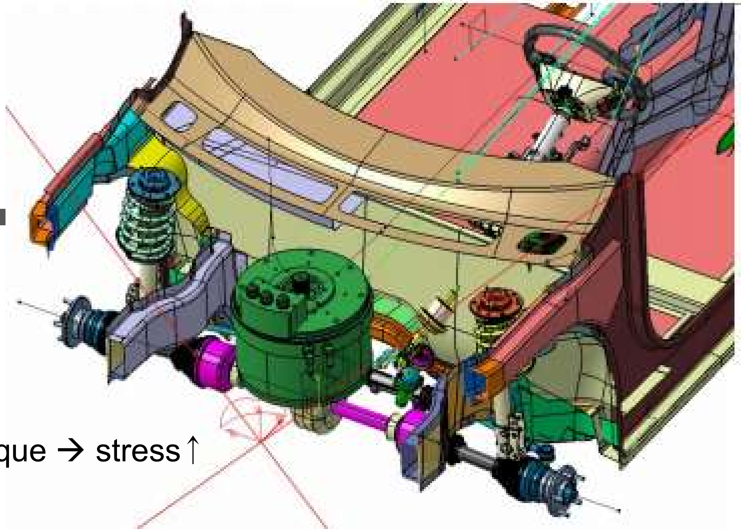
Vehicle Package Development

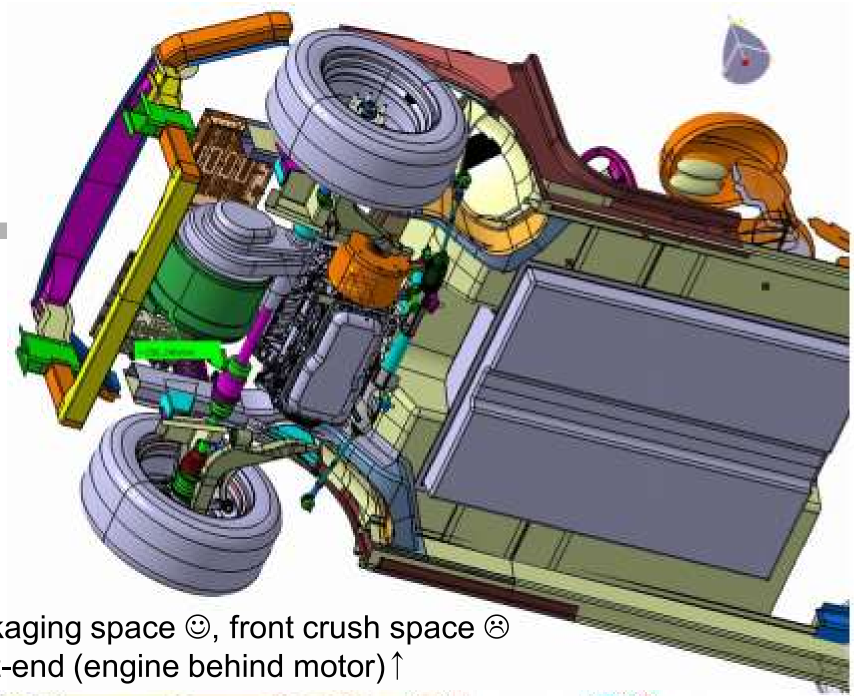
- Electric Drive
- Battery
- Fuel Cell and Hydrogen Storage
- Engine and Generator
- Front Suspension Designs
- Rear Suspension Designs
- FSV Suspension: Decision Matrix
- FSV Suspension: Layout
- FSV Suspension Characteristics

Electric Drive

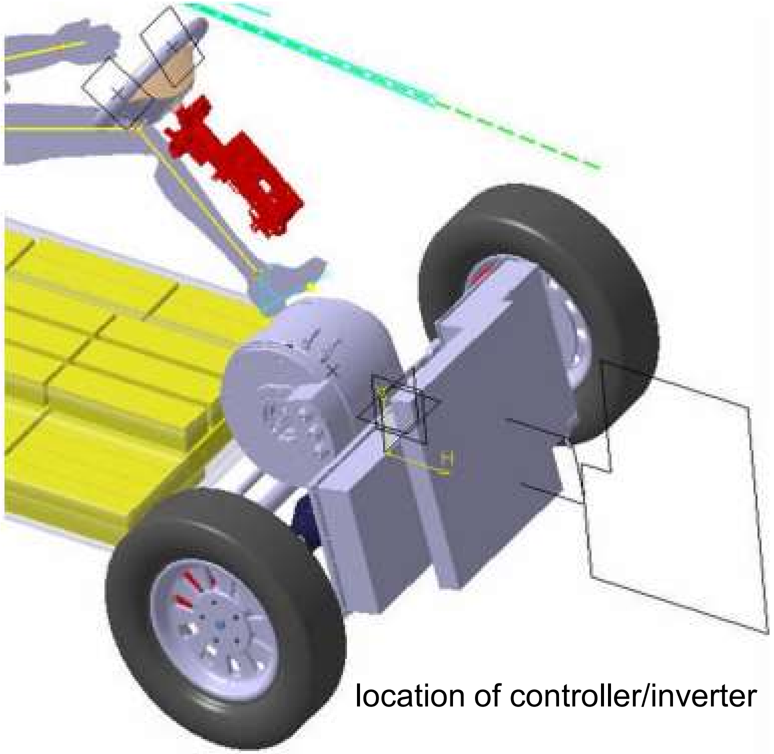
- Motor Vertical - in Line with Axle Centerline
- Motor Horizontal: Front of Axle Centerline
- Motor Horizontal: Rear of Axle Centerline
- Motor Horizontal: Inverter/Controller on Top
- Motor: Integrated Design Concept
- Motor: Final Optimised Design
  - Optimized utilization of underhood space resulting in a significantly short front-end (compared to vehicles in its class)
  - Integrated motor assembly
  - Optimized vehicle balance achieved due to optimized location of the vehicle's center of gravity



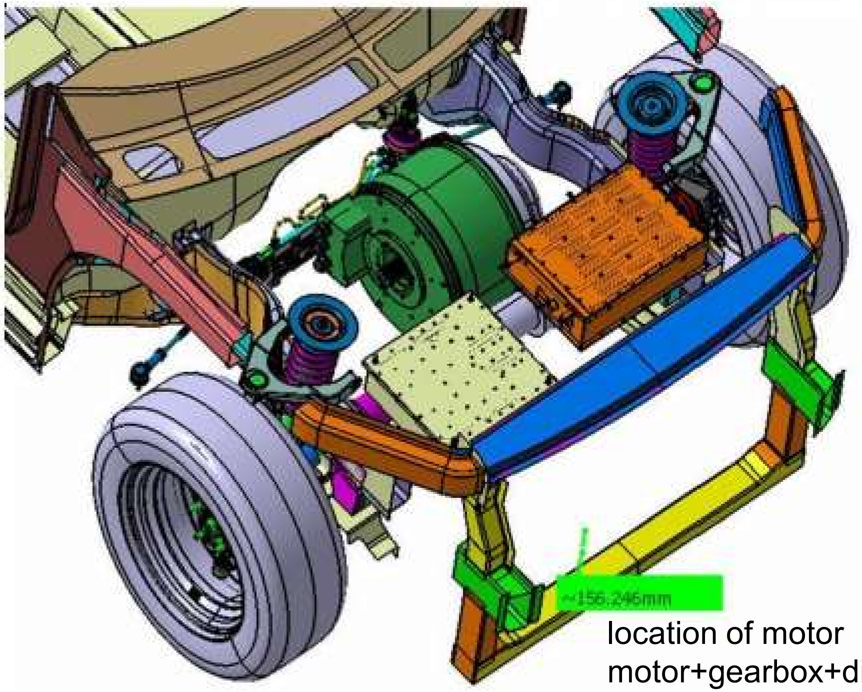
torque → stress↑



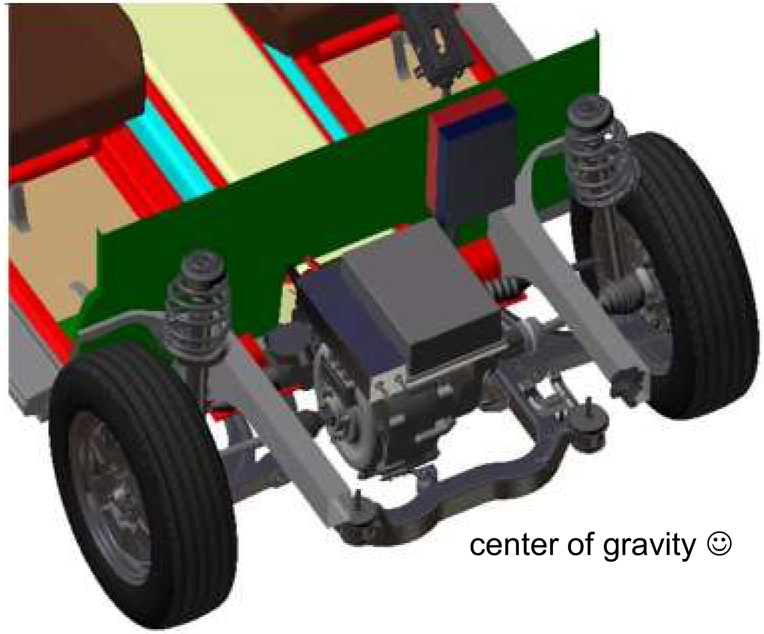
packaging space ☺, front crush space ☹
front-end (engine behind motor)↑



location of controller/inverter

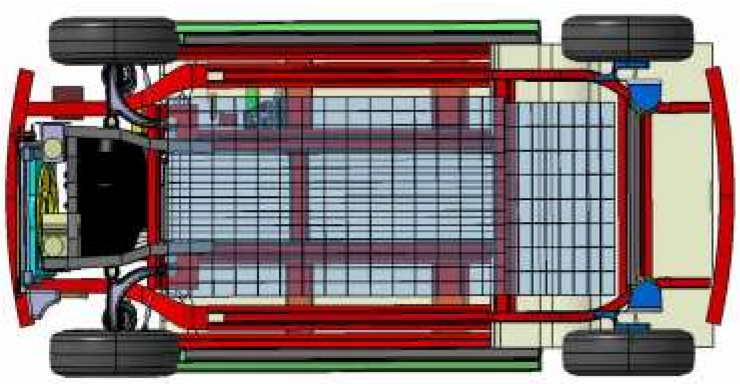


location of motor
motor+gearbox+differential

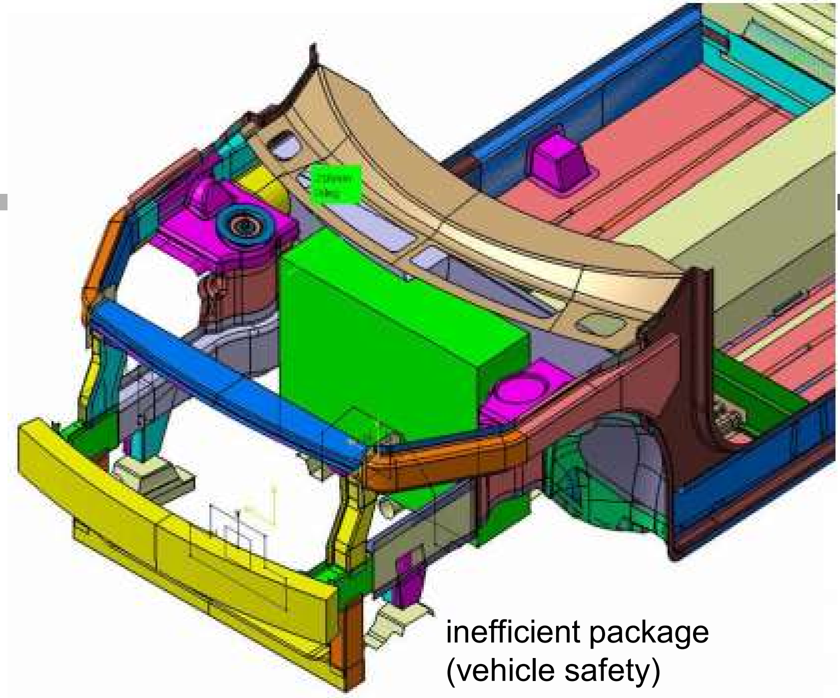

center of gravity ☺

Battery

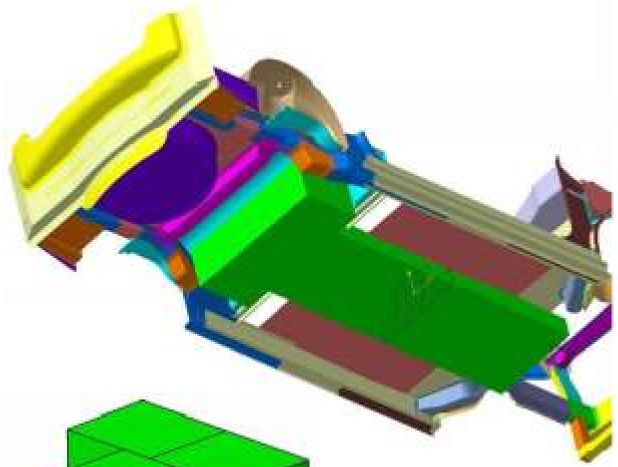
- Single Large Underfloor Battery
- Two Pack Design: Tunnel area and Underhood
- T-Shaped Pack: Preliminary Design
- T-Shaped Pack: Refined
- T-Shaped Pack: Reorganized Cell Arrangement
- T-Shaped Pack: Under-seat Pods
- T-Shaped Pack: Refined with Accessories
  - Coverplate, Tray, Bulk heads, Separators, Aero package
- T-Shaped Pack and Sub-Pack: Final design
- I-Shaped Pack: Packaging Impact
  - Range: 250 (35) → 500km (66kWh)
- Future Battery Pack and its impact to FSV Structure

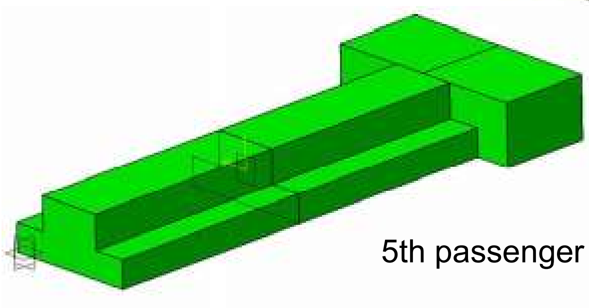


35kWh, floor height 75mm↑ → drag↑

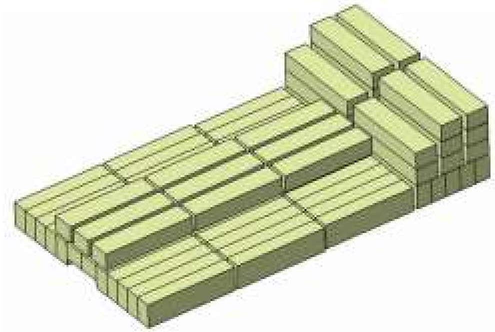


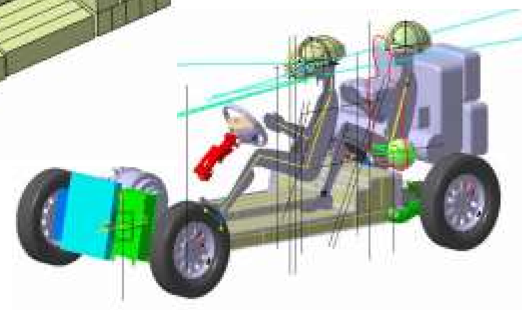
inefficient package
(vehicle safety)



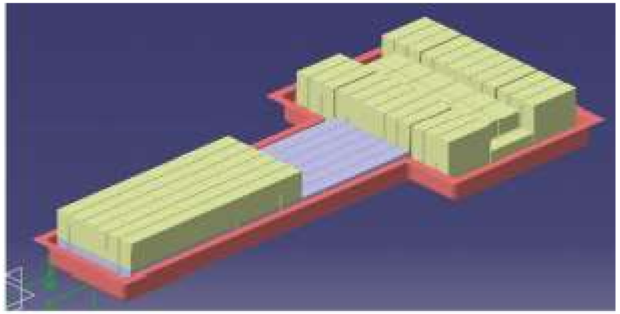


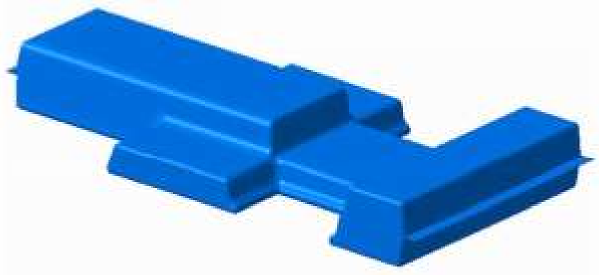
5th passenger seating

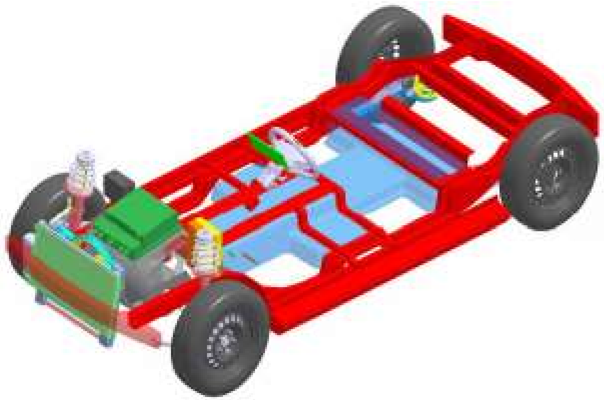




rear passenger seating position: 50mm↑





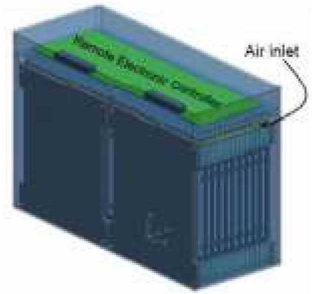


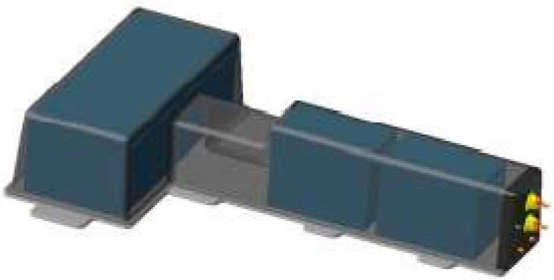
individual modules evenly throughout the pack

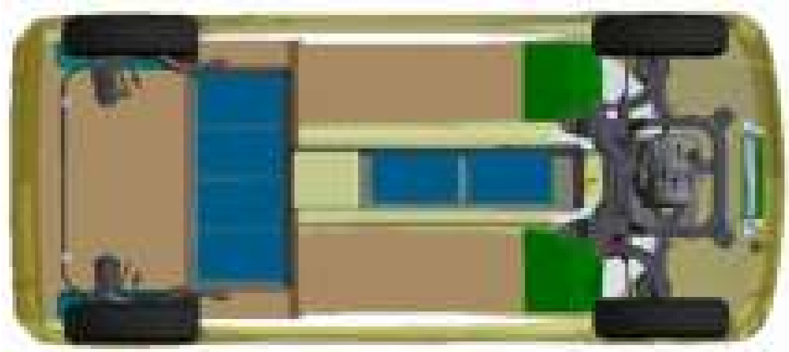
cooling characteristics

– Coverplate, Tray, Bulk heads, Separators, Aero package

FSV Battery Pack	Cell	Sub-Pack	Battery Pack
	468	6	1
Size [l]	0.28	34.5	271
Mass [kg]	0.55	49.1	345
Capacity [kWh]	0.075	5.8	34.9
Energy Density [kWh/kg]	0.14	0.12	0.10

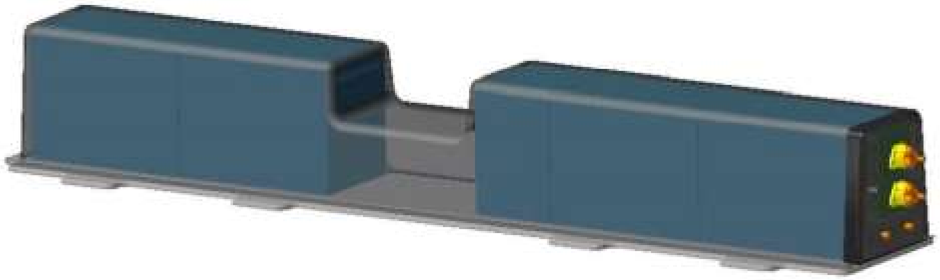


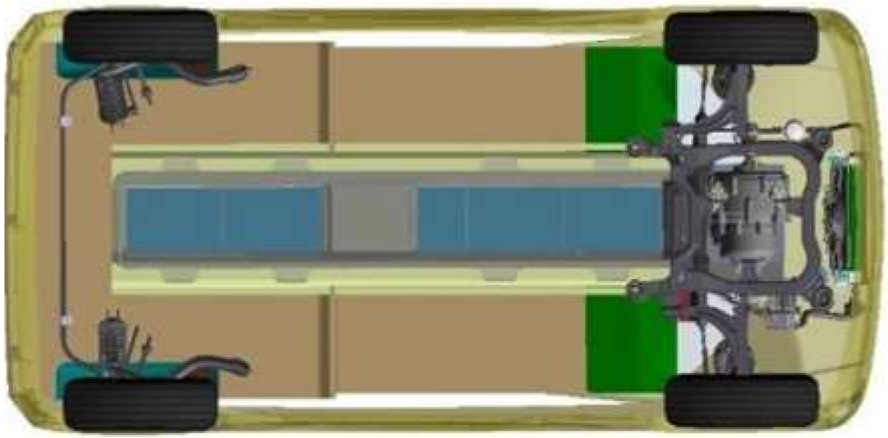


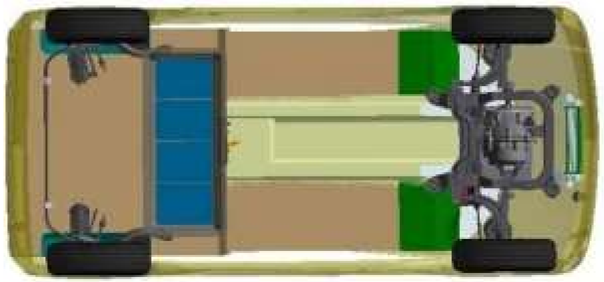


– Range: 250 (35) → 500km (66kWh)

FSV Battery Pack (Same Energy as NEDO3 Target)	Cell	Sub-Pack	Battery Pack
	240	4	1
Size [l]	0.28	25.4	133
Mass [kg]	0.55	37.8	177
Capacity [kWh]	0.275	16.5	66
Energy Density [kWh/kg]	0.5	0.44	0.37

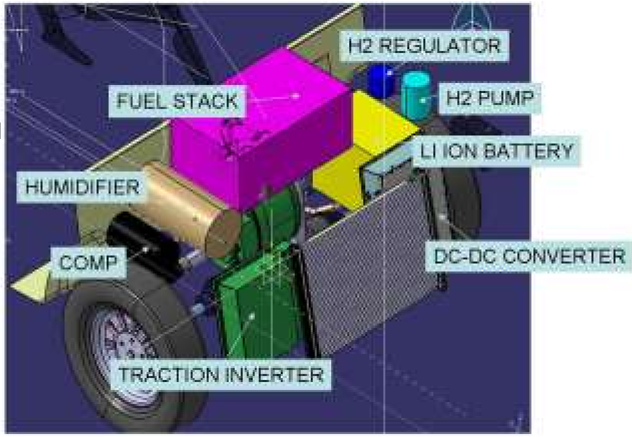


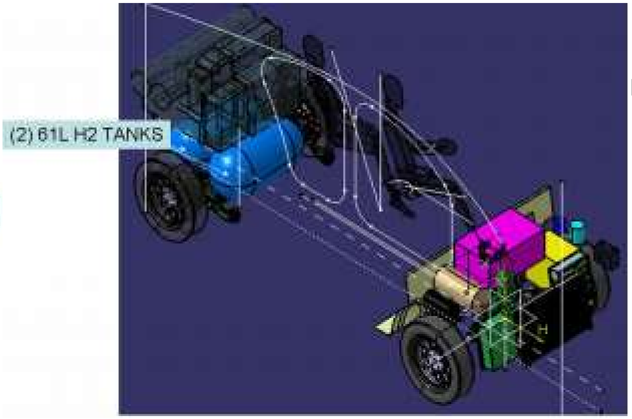


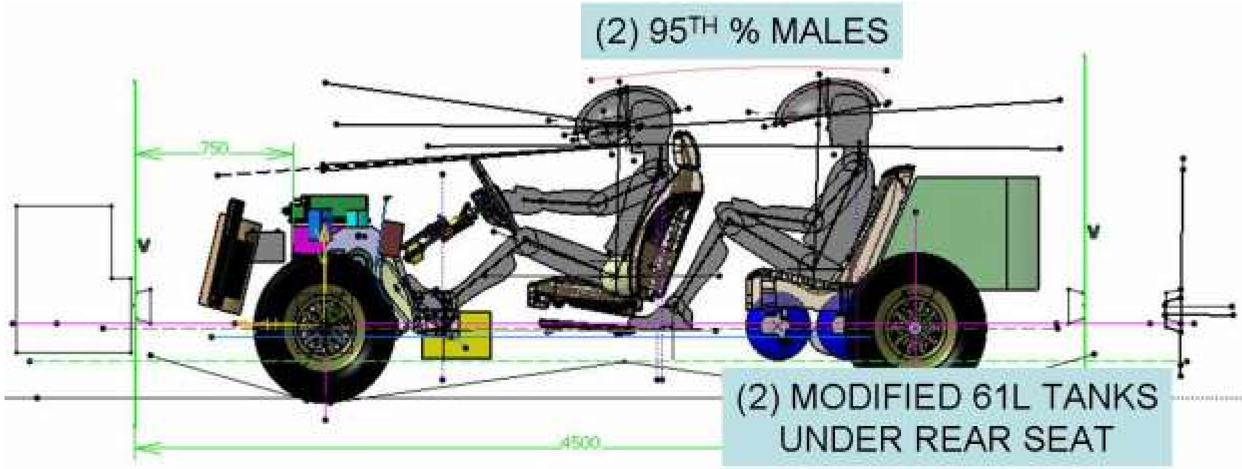


Fuel Cell and Hydrogen Storage

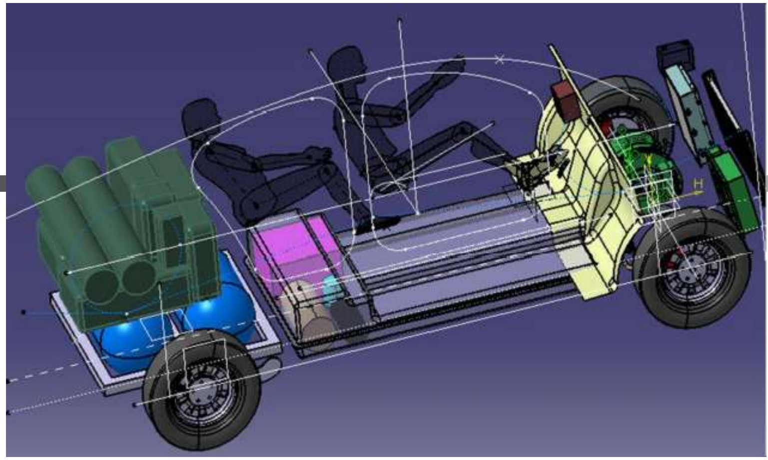
- Fuel Cell System in Engine Compartment
- Fuel Cell Stack under Inverter/Controller
- Fuel Stack under Rear Seat
- Fuel Cell Stack in Tunnel Area
- Fuel Cell System: Final Design with Tonji system



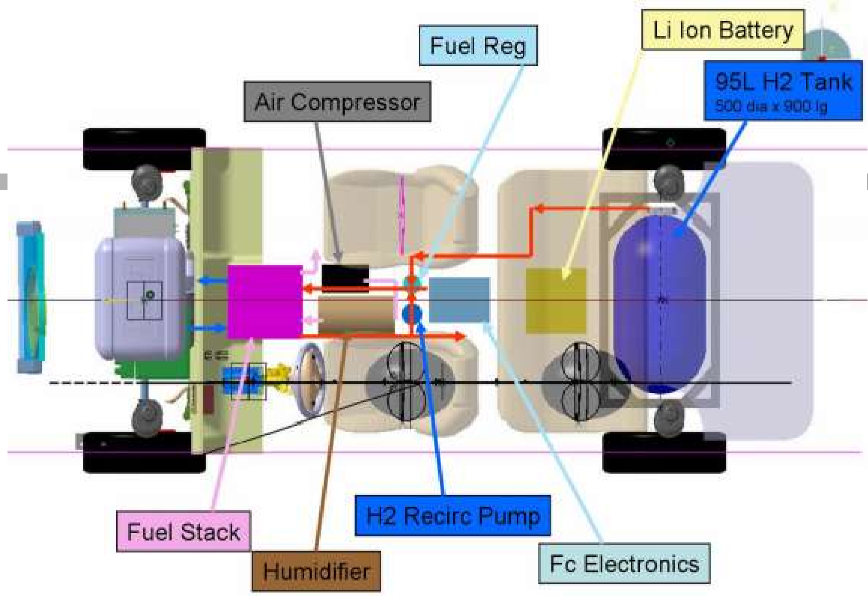


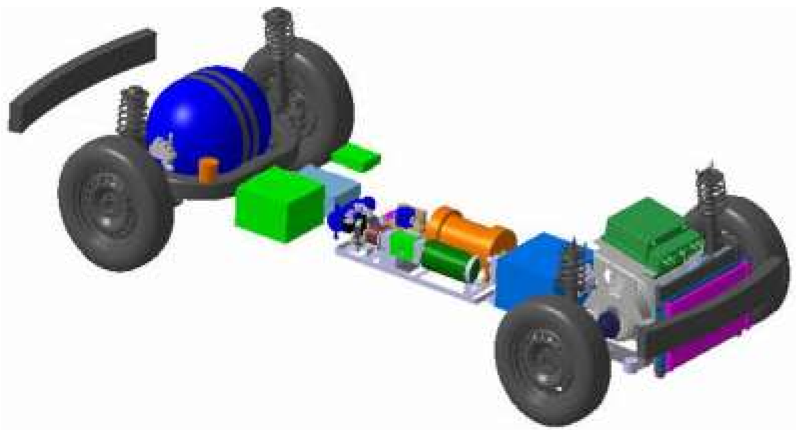


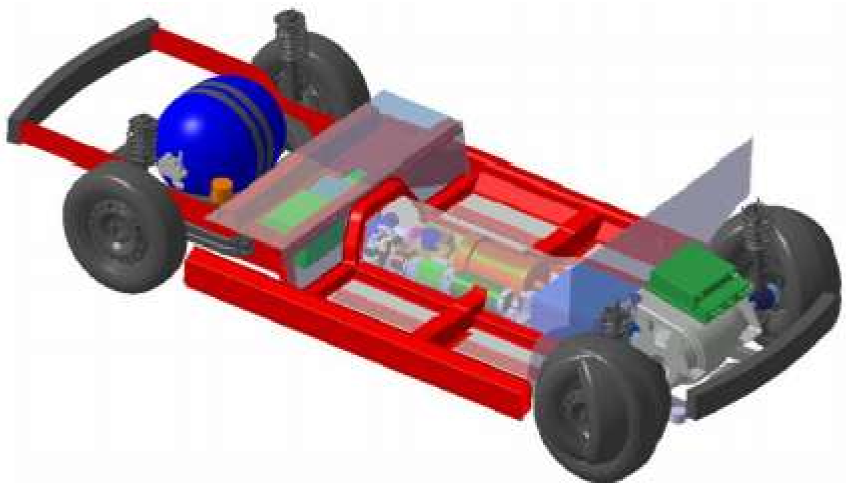
Frontal impact, FC components close to each other



common front-end for BEV and FCEV variants, inefficient positioning of the Li-ion battery pack

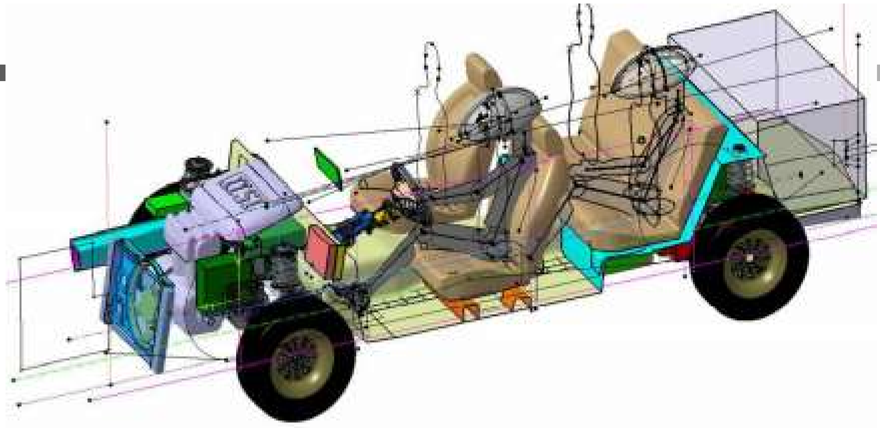




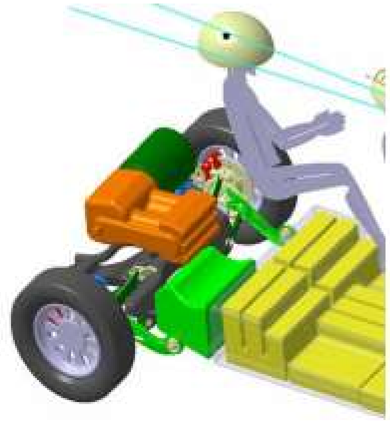


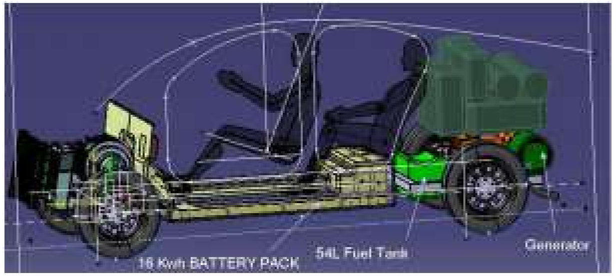
Engine and Generator

- Engine/Generator in Front
- Engine/Generator in Rear: Horizontal
- Engine/Generator in Rear: Vertical
- Engine/Generator in Rear: 17° tilt
- Engine/Generator in Rear: 45° tilt

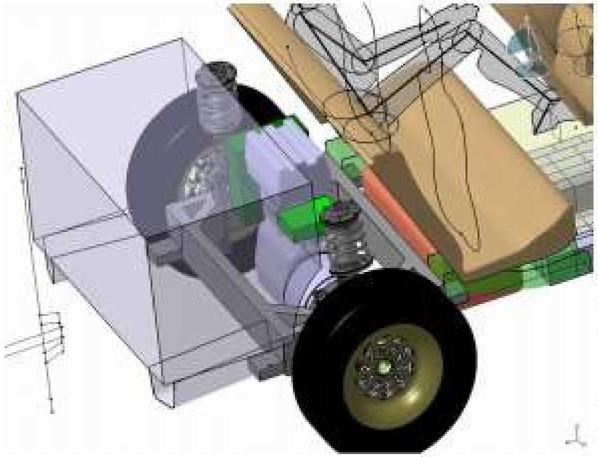


very common front-end, but cannot commonize
with other variants

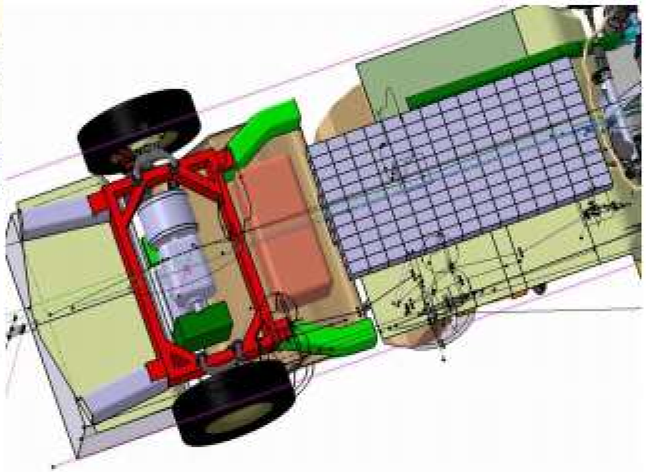


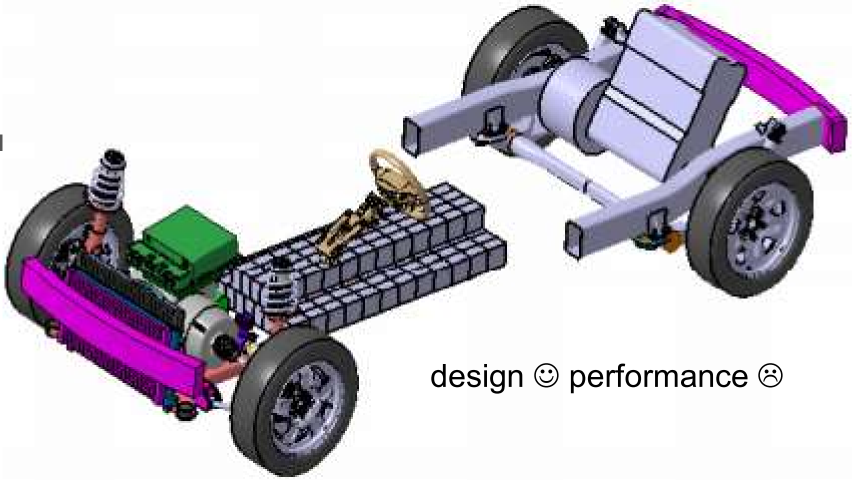


inefficient utilization of the engine characteristics (lubrication)

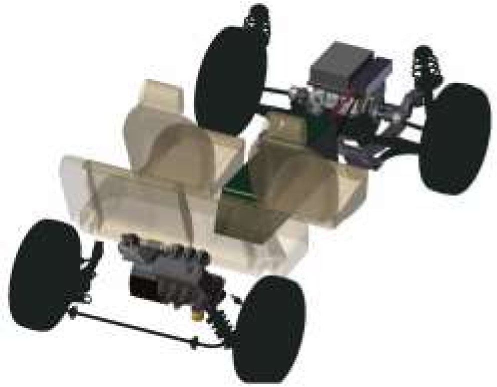


cargo volume



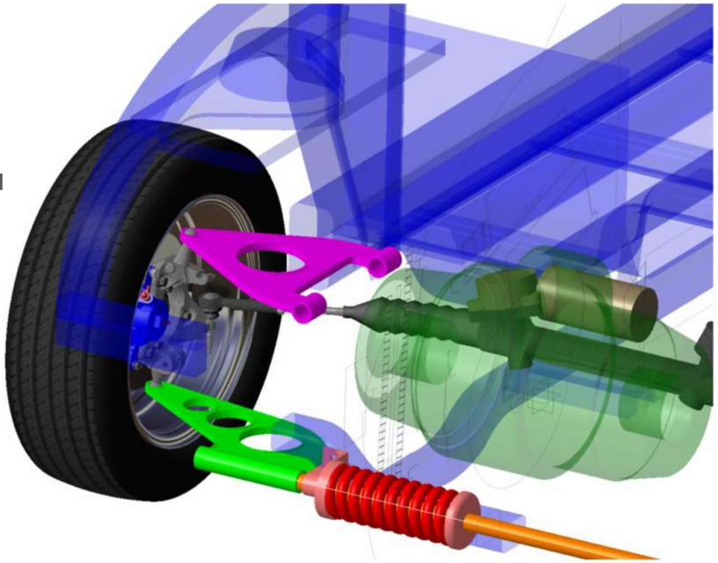


design ☺ performance ☹

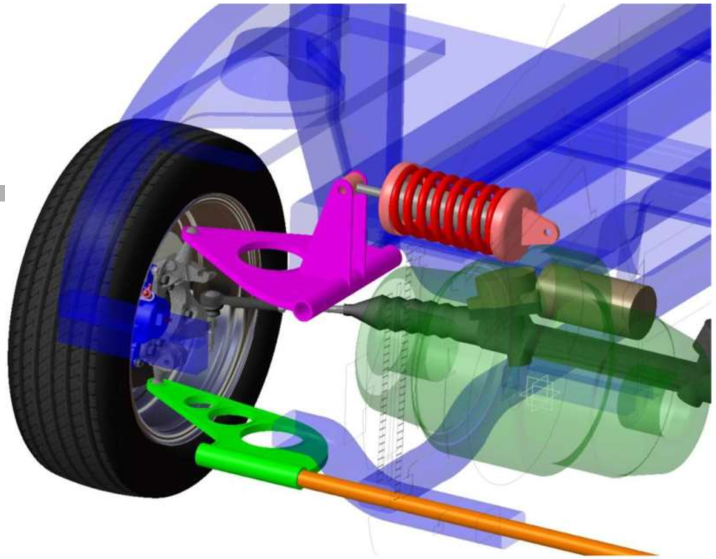


Front Suspension Designs

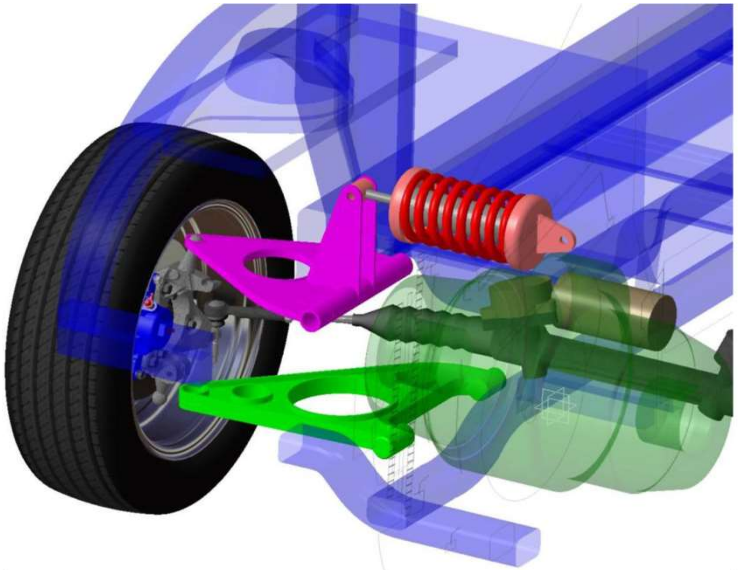
- Upper Control Arm / Lower Trailing Arm (sprung)
  - Design concept, Advantages, Disadvantages, Conclusion
- Upper Control Arm (sprung) / Lower Trailing Arm
- Upper Control Arm (sprung) / Lower Control Arm
- Upper Control Arm / Lower Control Arm (sprung)
- Horizontal Leaf Spring Design
- McPherson Strut / Lower Trailing Arm
- Conventional McPherson Strut



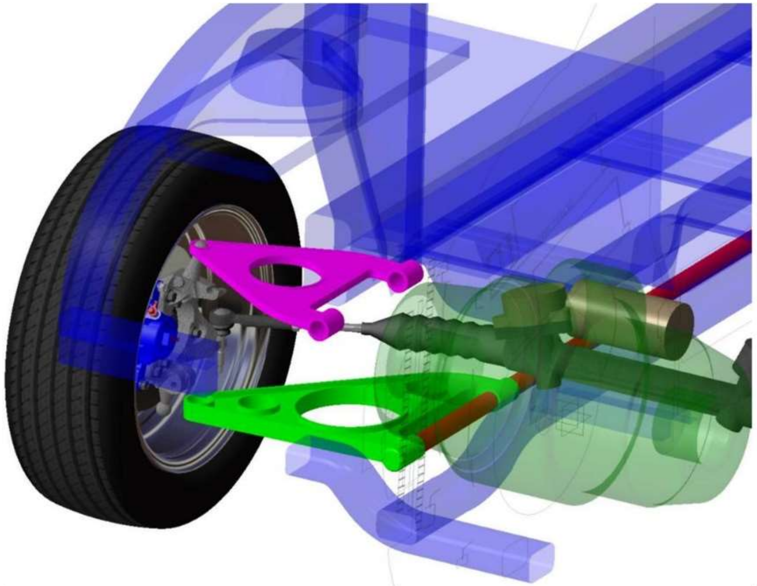
Upper Control Arm / Lower Trailing Arm (sprung)



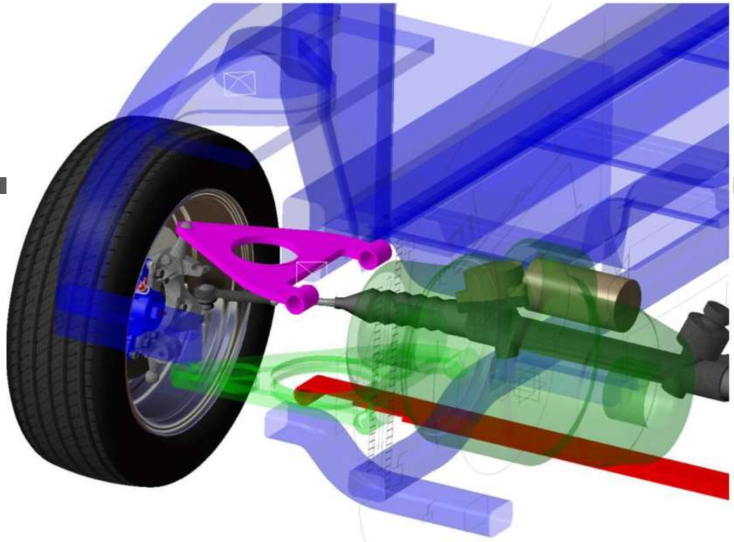
Upper Control Arm (sprung) / Lower Trailing Arm



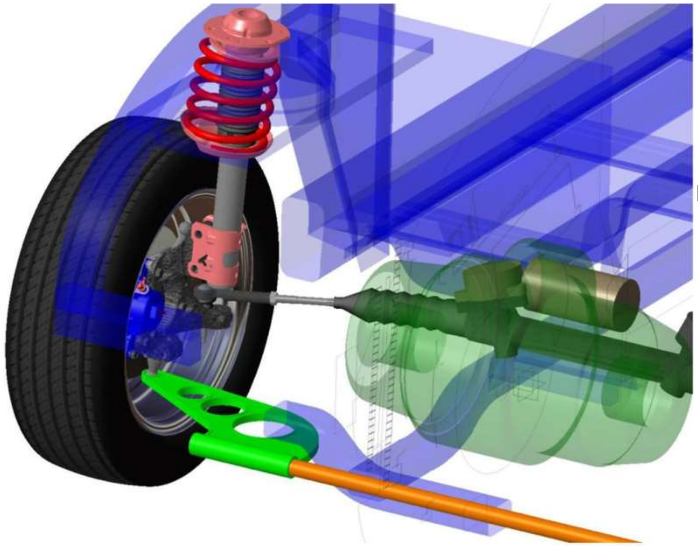
Upper Control Arm (sprung) / Lower Control Arm



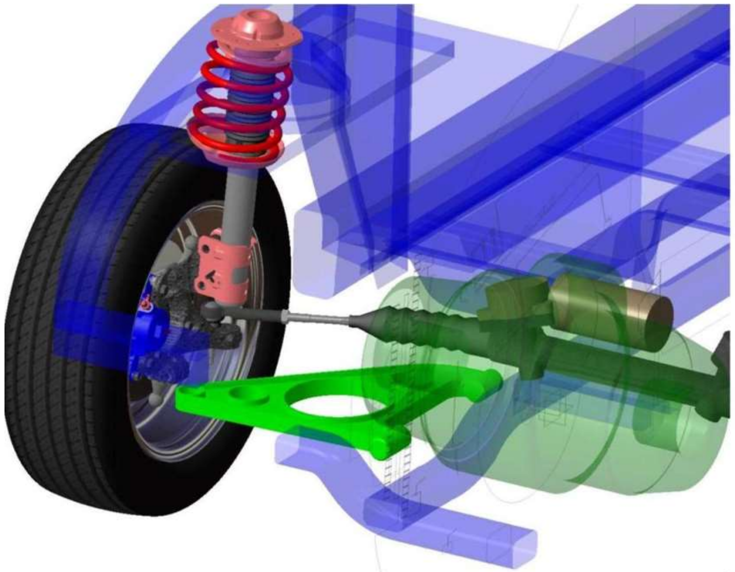
Upper Control Arm / Lower Control Arm (sprung)



Horizontal Leaf Spring Design



McPherson Strut / Lower Trailing Arm



Conventional McPherson Strut

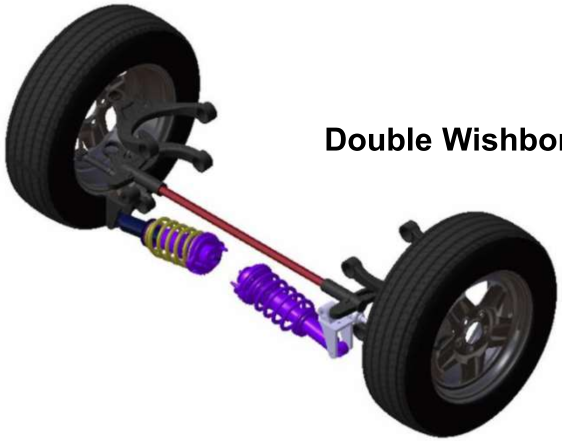
Rear Suspension Designs

- Twist Beam or Torsion Beam
- Passive Wheel
- Trailing Arm with 2 Camber Links
- Double Wishbone (SLA: Short and Long Arm)
- Chapman Strut / McPherson Strut
- H-Arm with Camber Control Link

Twist Beam or Torsion Beam

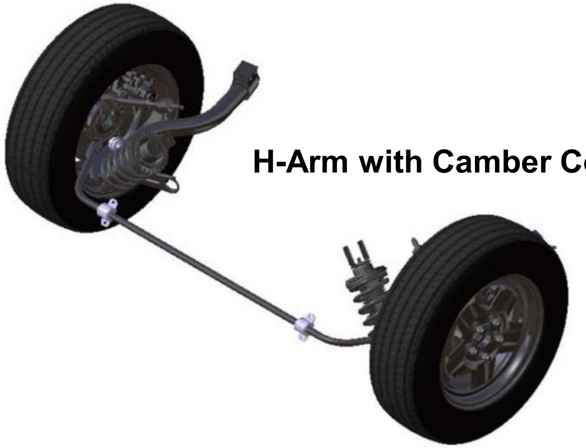
Passive Wheel

Trailing Arm with 2 Camber Links



Double Wishbone (SLA)

Chapman Strut / McPherson Strut



H-Arm with Camber Control Link

FSV Suspension: Decision Matrix

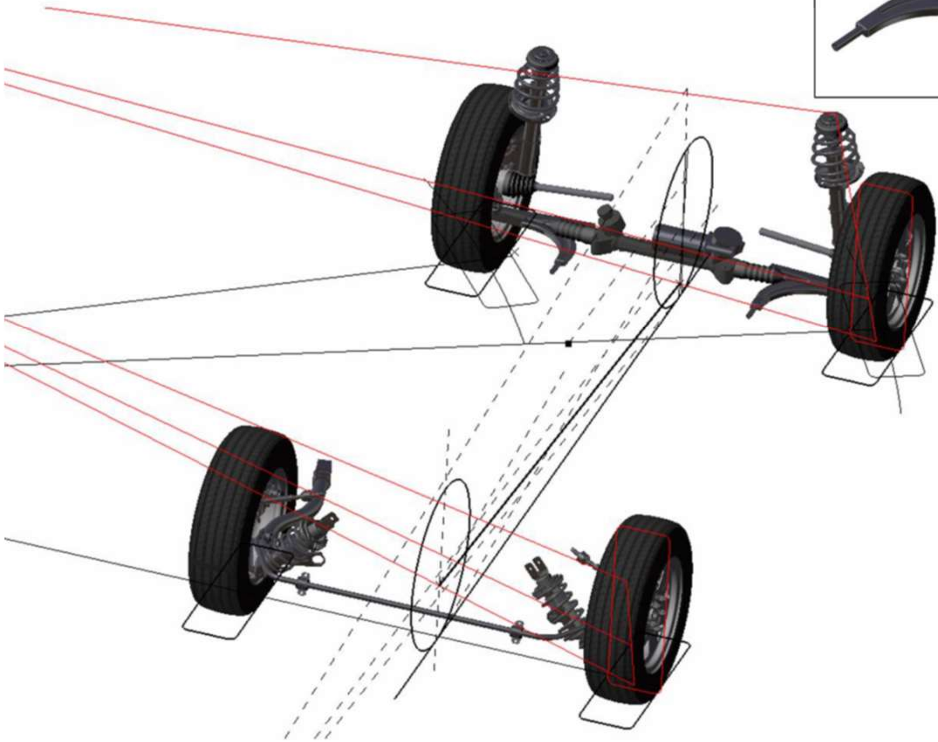
- Front: conventional McPherson strut
  - both the McPherson strut suspension options
  - minimal developmental investment cost and time
- Rear: H-arm with camber control link suspension
  - simple, light weight, cost effective, has a low part count, has acceptable kinematics
  - common on all the FSV variants (BEV, FCEV and PHEV)

Potential FSV Suspension Designs	Suspension Parameters						
	Kinematics	Packaging	Mass	Cost	number of parts	Design Complexity	Ranking
Upper Control Arm / Lower Trailing Arm (sprung)	++	O	−	−	+	−	3
Upper Control Arm (sprung) / Lower Trailing Arm	++	−	−	−	O	−	6
Upper Control Arm (sprung) / Lower Control Arm	++	−	−	−	−	−	7
Upper Control Arm / Lower Control Arm (sprung)	+	O	−	O	O	−	4
Leaf Spring	++	−	O	−	O	−	5
McPherson Strut / Lower Trailing Arm	+	+	+	+	++	+	1
Conventional McPherson strut	+	+	+	+	+	+	2

Potential FSV Suspension Designs	Suspension Parameters						
	Kinematics	Packaging	Mass	Cost	number of parts	Design Complexity	Ranking
Twist Beam or Torsion Beam	O	−	O	+	+	+	3
Passive Wheel	−	++	++	−−	+	−	5
Trailing Arm concept with 2 Camber links	+	+	−	O	O	−	6
Double Wishbone	+	+	O	O	O	−	4
Chapman strut / McPherson strut	O	+	+	+	+	+	2
H-Arm with Camber Control Link	+	+	+	+	+	+	1

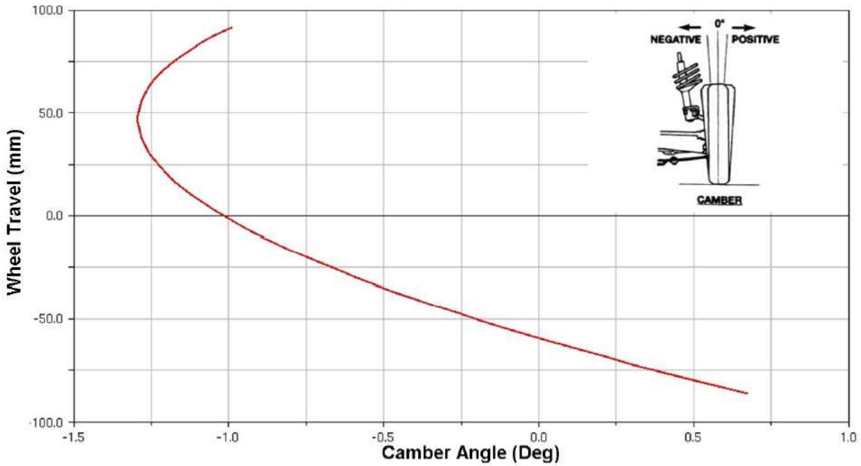
FSV Suspension: Layout

- conventional McPherson strut design
  - lower control arm: two piece design (hydroformed and stamped) with light weight steel of 2 mm gauge thickness
  - 1.56 kg only about 6% heavier than a similar sized aluminum

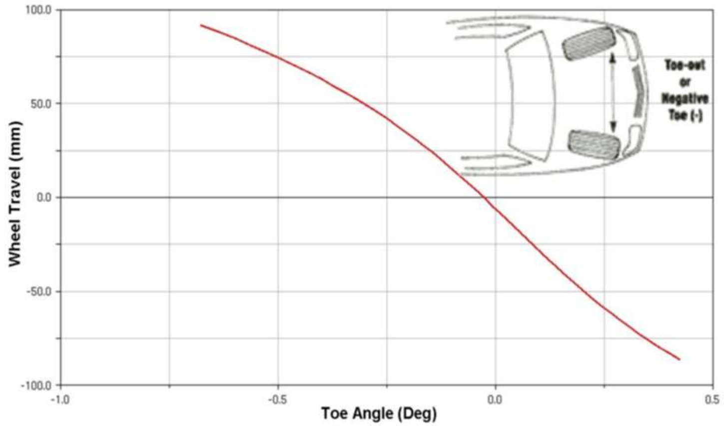


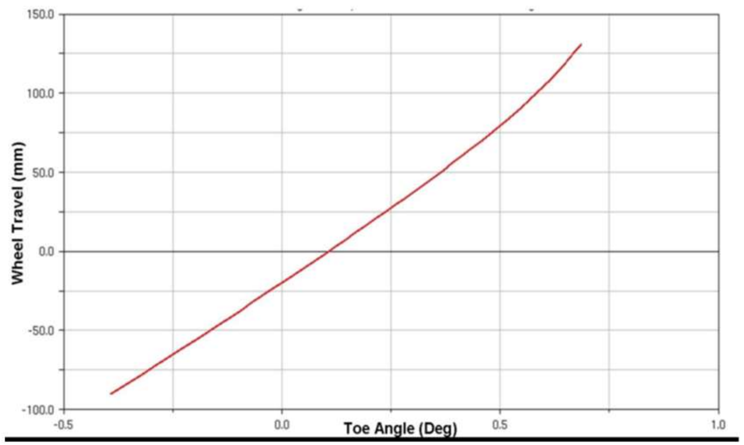
Suspension Characteristics

- Camber
  - Jounce (-)
    - Suspension compresses
    - Body roll
  - Rebound



- Toe Angle: Understeer
  - Front: Toe-in (+)





Sensitivity Analysis

- Battery Technology
- Motor Technology and Cooling
- Fuel Cell Technology

Battery Technology (1)

- Shift from Ni-MH to Li-Ion battery technology
  - Manufacturing cost and energy storage capacity advantages
  - Cylindrical cells connected in series (strings) and parallel, to achieve the voltage levels and desired storage capacity
  - Require safety measures for crash and service
- Temperature control of individual cells and battery packs
  - Increase durability
  - Acceptable operation performance under extreme climate conditions

	Battery Capacity	Mass	Energy Density		Year
			Pack	Cell	
	kWh	Kg	wh/kg	wh/kg	
Mini e	35	260	135		2009
Tesla	53	430	123	200	2004
EnerDel	27	283	95		2009
I MiEV	16	200.0	80	150	2007
GM Volt	16	170.1	94		2010

Battery Technology (2)

Battery Technology Assessment

		Status 2008	Prediction 2015-2020	Selection FSV
Dominating Technology		Ni-MH	Li-Ion	Li-Ion
Power Density	kW/kg	1.1	1-3	2.0
Energy Density	Wh/kg	45	90 - 170	130

Battery Pack Technology Assessment

Capacity	kWh	10 (max)	1.5 - 40	2.3 - 35
Cost	$ USD/ kWh	500	400-700	450

Future Steel Vehicle Concept

	Capacity (kWh)	Weight (kg)	Volume (Liters)	Cost ($ USD)
$PHEV_{20}$	5	58.2	47	$2,346
$PHEV_{40}$	11.7	136.5	103	$5,365
BEV	35	346.5	280	$15,895
FCEV	2.3	27.3	25	$1,503

FSV BEV recommended specification

FSV Battery Pack	Cell	Sub-Pack	Battery Pack
	372	6	1
Size [l]	0.28	27.4	215
Mass [kg]	0.55	39	274
Capacity [kWh]	0.093	5.8	34.7
Energy Density [kWh/kg]	0.17	0.15	0.13

Table 7.4: *FSV-1 BEV battery specifications (new pack)*

0.14 (2010)

20% degradation

FSV Battery Pack	Cell	Sub-Pack	Battery Pack
	372	6	1
Size [l]	0.28	27.4	215
Mass [kg]	0.55	39.0	274
Capacity [kWh]	0.075	4.6	27.8
Energy Density [kWh/kg]	0.14	0.12	0.10

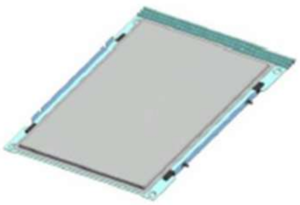
Table 7.5: *FSV-1 BEV battery specifications (end of life)*

FSV Battery Pack	Cell	Sub-Pack	Battery Pack
	468	6	1
Size [l]	0.28	34.5	271
Mass [kg]	0.55	49.1	345
Capacity [kWh]	0.075	5.8	34.9
Energy Density [kWh/kg]	0.14	0.12	0.10

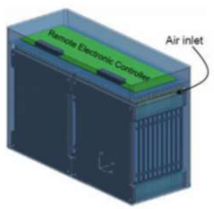
Table 7.6: *FSV-1 BEV final battery specifications (end of life)*

FSV Battery Pack (Same Energy as NEDO3 Target)	Cell	Sub-Pack	Battery Pack
	240	4	1
Size [l]	0.28	25.4	133
Mass [kg]	0.55	37.8	177
Capacity [kWh]	0.275	16.5	66
Energy Density [kWh/kg]	0.5	0.44	0.37

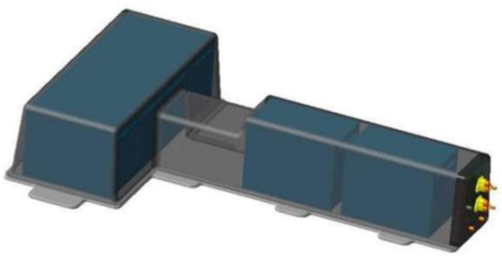
Table 7.7: *FSV-1 Battery specs with NEDO3 targets*



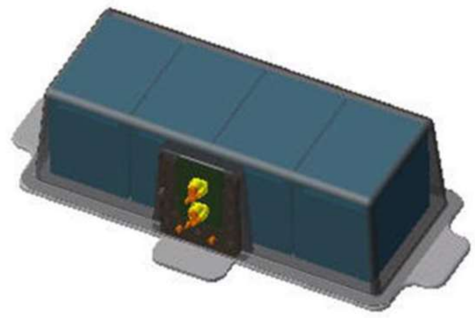
Cell



Sub-pack



Battery Pack

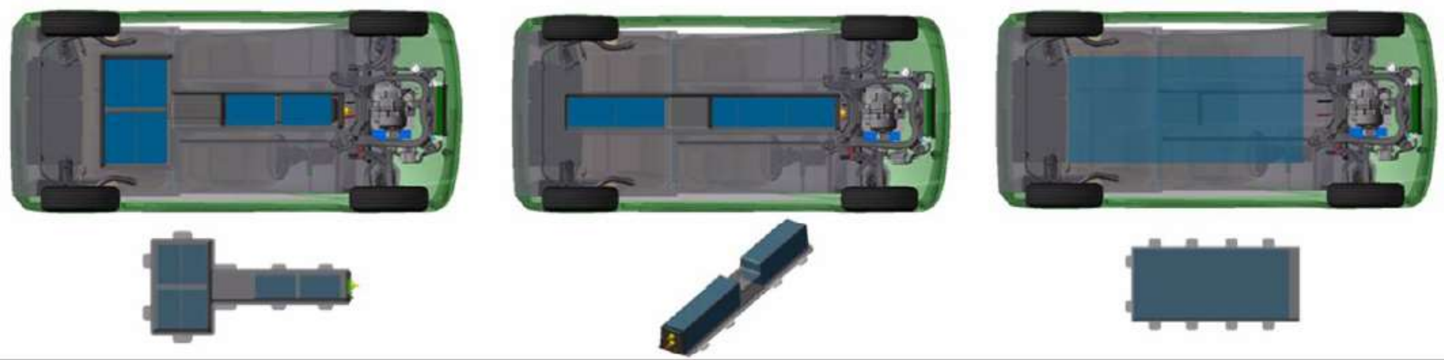


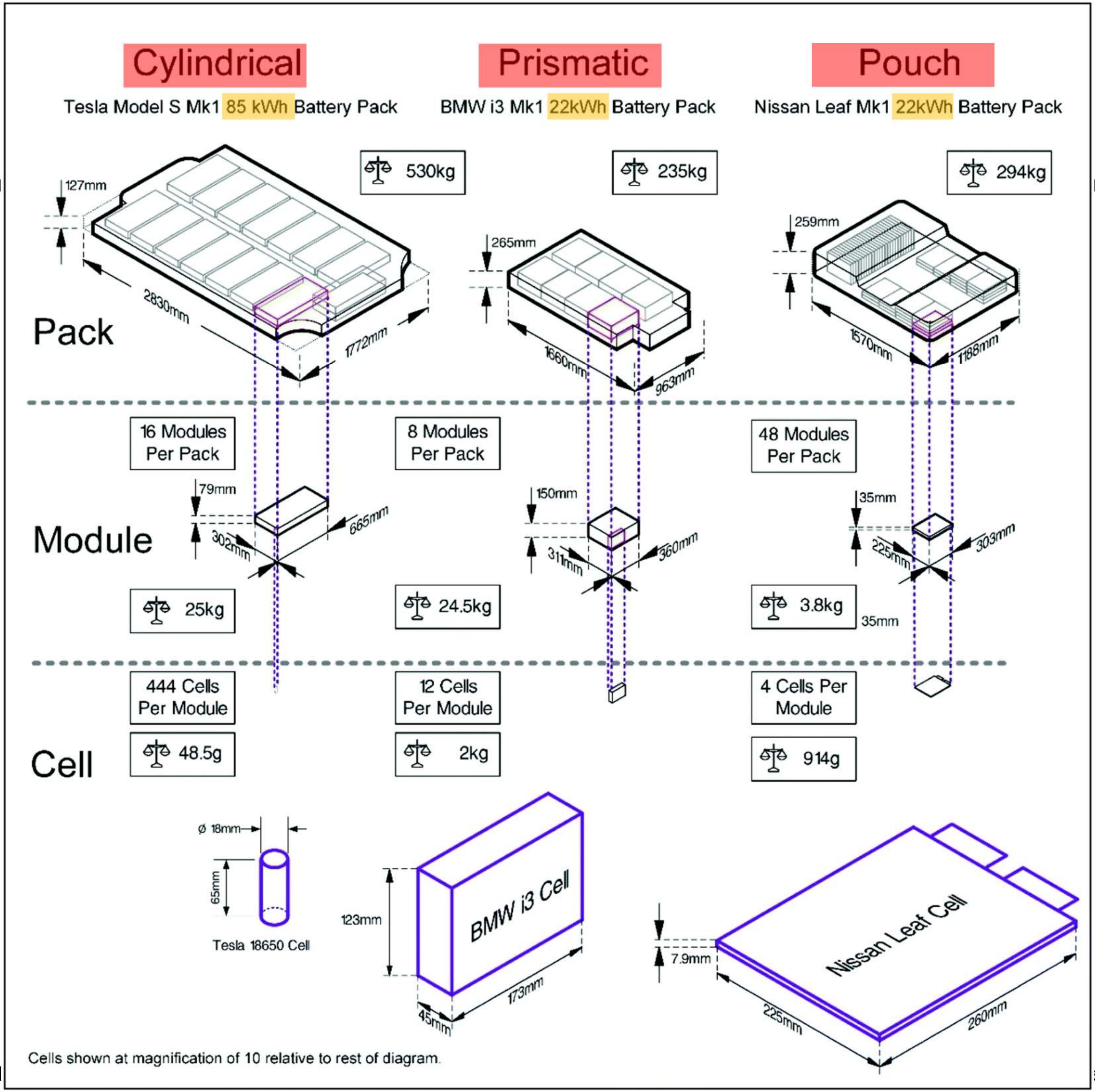
Case Study Results

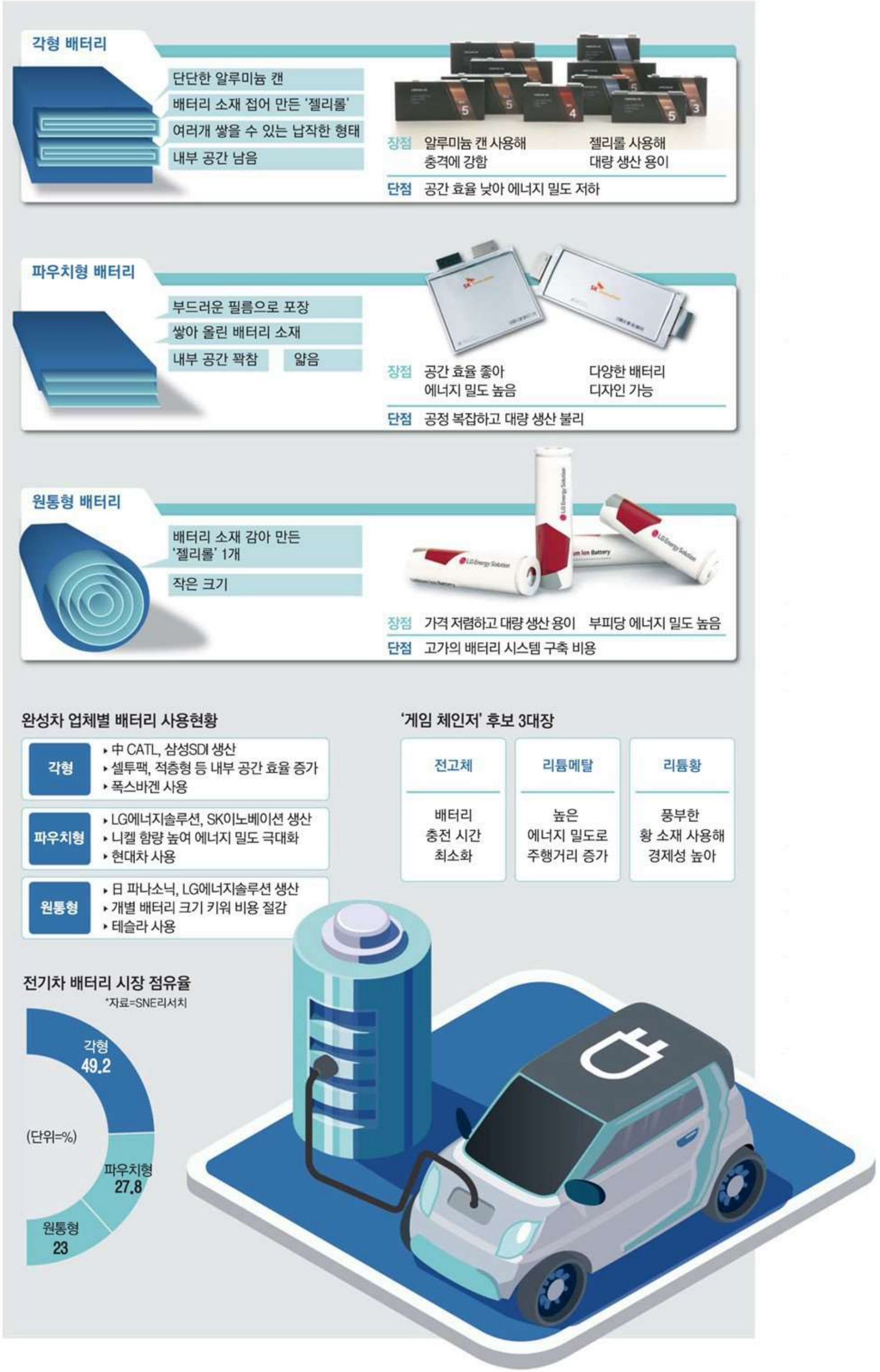
	Energy density kWh/kg		Useful energy at Wheels		Energy Required to Drive 1 km	Battery Size (DOD 80%)	Fuel (or battery) Mass to Drive 500 km (250	Electric Power train (motor, converter/ controller, transmission,	Total Powertrain Mass for 500 km (250 km) Driving
	Cell	Pack	Efficiency	kWh/kg	kWh	kWh	kg	kg	kg
Li-ion Batteries Current Technology 2008	0.14	0.10	85%	0.09	0.095	34.9	335	134	469
Case 1 - FSV Technology (2015-2020)	0.17	0.13	85%	0.11	0.095	34.9	274	134	408
Case 2 - 80% of Li Ion Limit	1.11	0.83	85%	0.71	0.090	66.2	79	134	213
Case 3 - Li-ion to compete with Gasoline for Cars (same powertrain mass)	0.51	0.38	85%	0.33	0.095	69.9	182	134	316
Case 4 - Li-ion to compete with H2 at 700 bar for Cars (same powertrain mass)	0.46	0.34	85%	0.29	0.095	69.9	203	134	337
Case 6 - NEDO & DOE Step 1 (2015)	0.15	0.11	85%	0.10	0.095	34.9	310	134	444
Case 7 - NEDO & DOE Step 2 (2020)	0.20	0.15	85%	0.13	0.095	34.9	233	134	367
Case 8 - NEDO Step 3 (2030)	0.50	0.38	85%	0.32	0.090	66.2	176	134	310

Battery Shape Assessment

Battery Shape	Available Under-Floor Volume (l)	Battery Capacity kWh New (End of life)	Range (kM)	Damage/Risk due to Crash Tests		
				Frontal	Rear	Side
	300	54 (43)	455 (360)	Low	Low	Medium
	175	30 (24)	250 (200)	Low	Medium	Low
	260	46 (37)	385 (310)	Low	Low	Medium




Cylindrical
Tesla Model S Mk1 85 kWh Battery Pack
Prismatic
BMW i3 Mk1 22kWh Battery Pack
Pouch
Nissan Leaf Mk1 22kWh Battery Pack
530kg
235kg
294kg
127mm
265mm
259mm
Pack
2830mm
1772mm
1660mm
963mm
1570mm
1188mm
16 Modules Per Pack
8 Modules Per Pack
48 Modules Per Pack
79mm
150mm
35mm
Module
302mm
665mm
311mm
360mm
225mm
303mm
25kg
24.5kg
3.8kg
35mm
444 Cells Per Module
12 Cells Per Module
4 Cells Per Module
Cell
48.5g
2kg
914g
ø 18mm
65mm
Tesla 18650 Cell
123mm
BMW i3 Cell
45mm
173mm
7.9mm
Nissan Leaf Cell
225mm
260mm
Cells shown at magnification of 10 relative to rest of diagram.



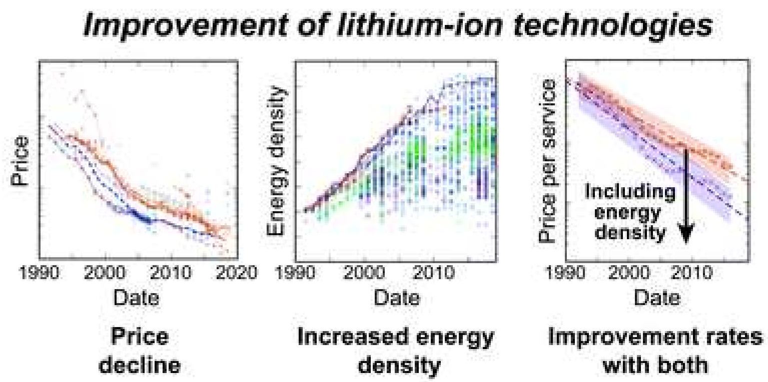
각형 배터리
단단한 알루미늄 캔
배터리 소재 접어 만든 '젤리롤'
여러개 쌓을 수 있는 납작한 형태
내부 공간 남음
장점 알루미늄 캔 사용해 충격에 강함
젤리롤 사용해 대량 생산 용이
단점 공간 효율 낮아 에너지 밀도 저하
파우치형 배터리
부드러운 필름으로 포장
쌓아 올린 배터리 소재
내부 공간 꽉참
얇음
장점 공간 효율 좋아 에너지 밀도 높음
다양한 배터리 디자인 가능
단점 공정 복잡하고 대량 생산 불리
원통형 배터리
배터리 소재 감아 만든 '젤리롤' 1개
작은 크기
장점 가격 저렴하고 대량 생산 용이
부피당 에너지 밀도 높음
단점 고가의 배터리 시스템 구축 비용
완성차 업체별 배터리 사용현황
각형
▸ 中 CATL, 삼성SDI 생산
▸ 셀투팩, 적층형 등 내부 공간 효율 증가
▸ 폭스바겐 사용
파우치형
▸ LG에너지솔루션, SK이노베이션 생산
▸ 니켈 함량 높여 에너지 밀도 극대화
▸ 현대차 사용
원통형
▸ 日 파나소닉, LG에너지솔루션 생산
▸ 개별 배터리 크기 키워 비용 절감
▸ 테슬라 사용
'게임 체인저' 후보 3대장
전고체
배터리 충전 시간 최소화
리튬메탈
높은 에너지 밀도로 주행거리 증가
리튬황
풍부한 황 소재 사용해 경제성 높아
전기차 배터리 시장 점유율
*자료=SNE리서치
(단위=%)
각형 49.2
파우치형 27.8
원통형 23

Analysis

Re-examining rates of lithium-ion battery technology improvement and cost decline

Micah S. Ziegler and Jessika E. Trancik

We examine how quickly lithium-ion technologies have improved and find that previous metrics can underestimate improvement rates for stationary storage applications.



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Energy Environ. Sci., 2021, Advance Article
https://doi.org/10.1039/D0EE02681F

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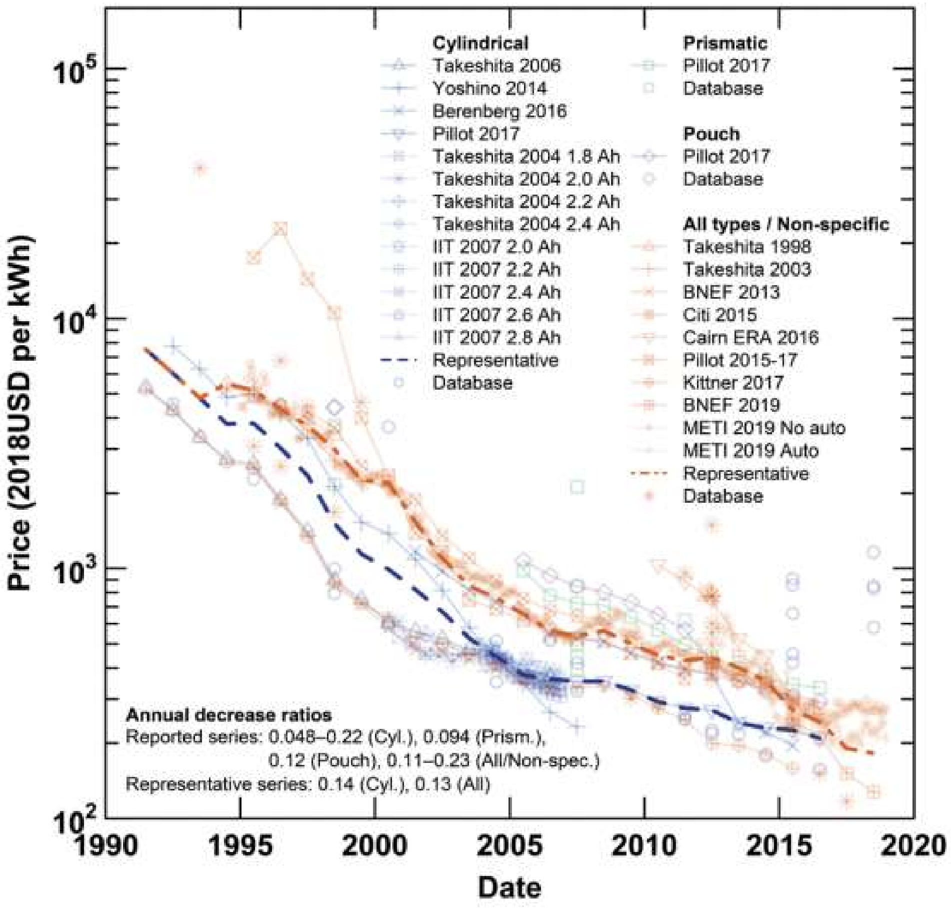
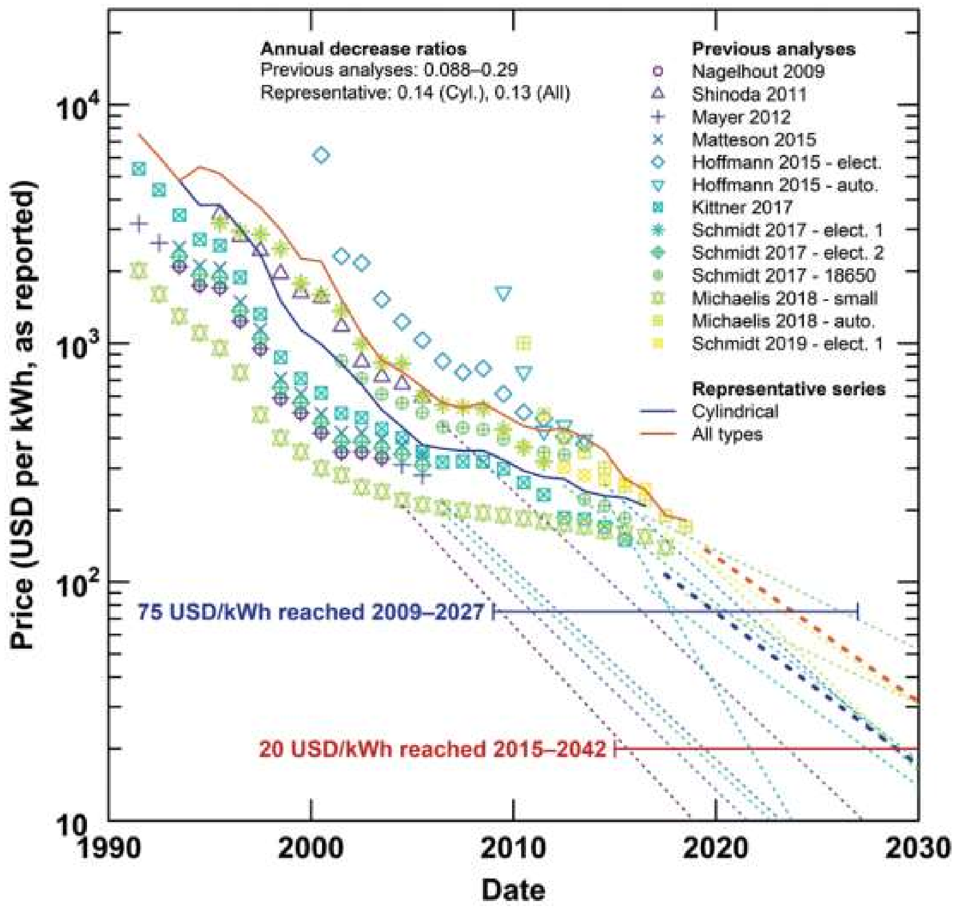
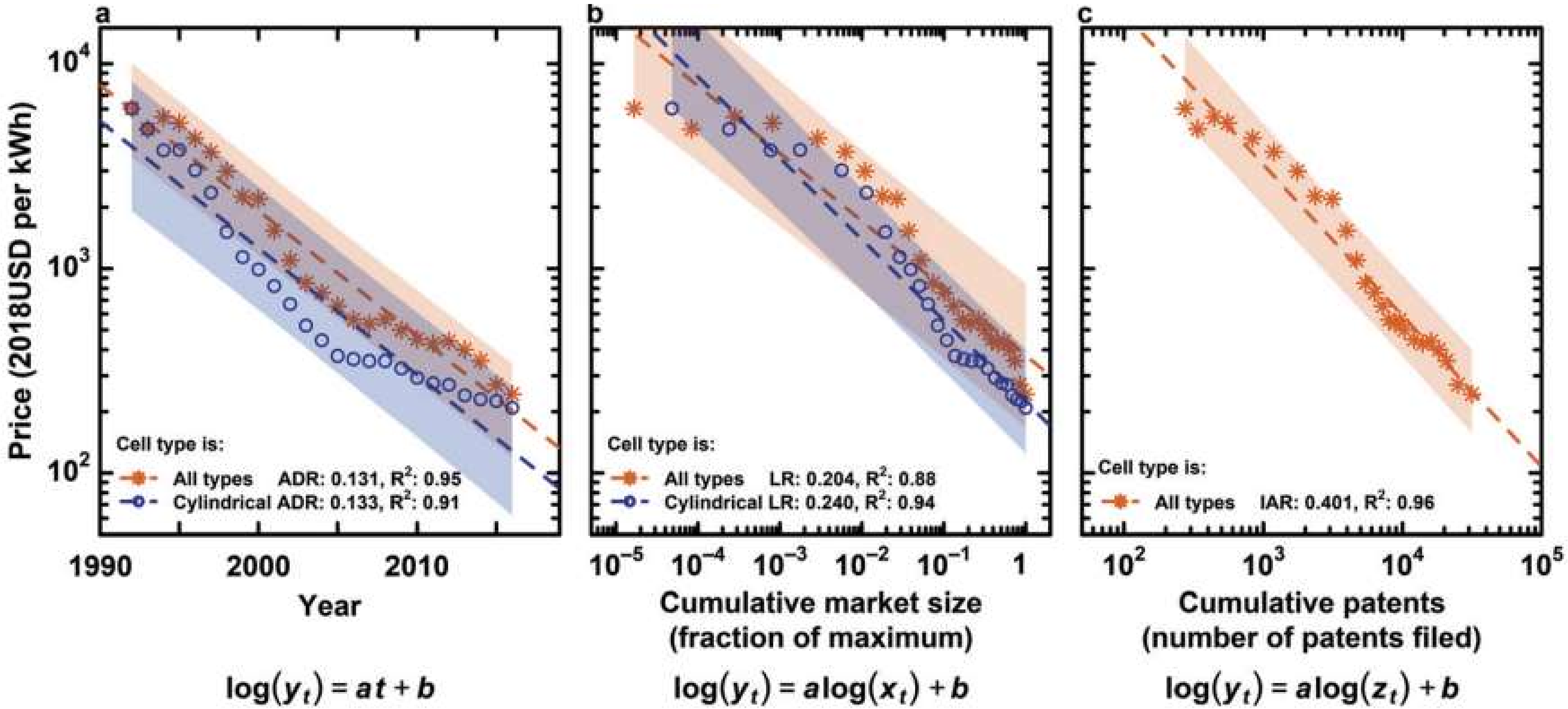
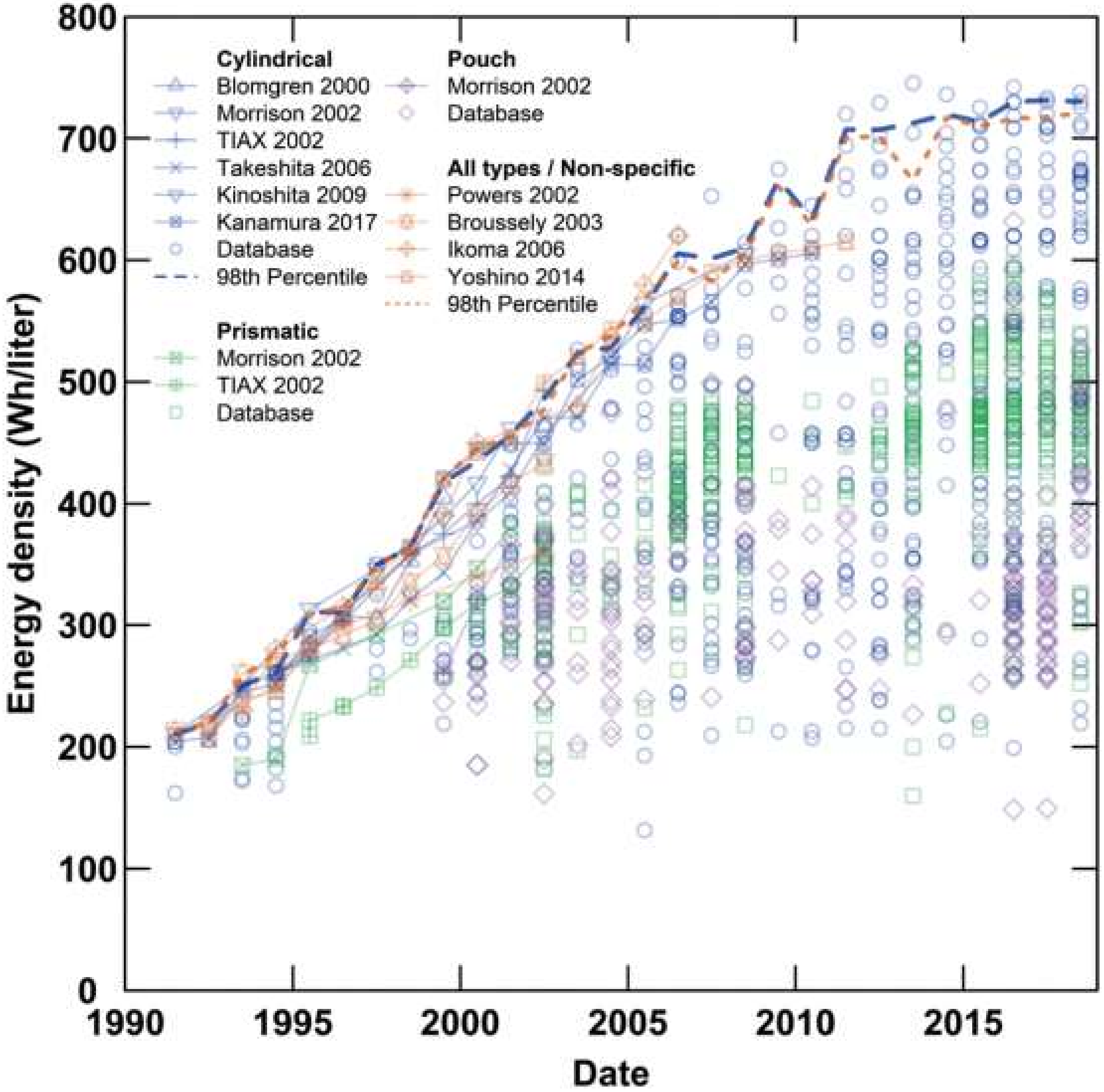
Lithium-ion Cell Prices






a
b
c
Price (2018USD per kWh)
Cell type is:
All types ADR: 0.131, R^2: 0.95
Cylindrical ADR: 0.133, R^2: 0.91
All types LR: 0.204, R^2: 0.88
Cylindrical LR: 0.240, R^2: 0.94
All types IAR: 0.401, R^2: 0.96
Year
Cumulative market size (fraction of maximum)
Cumulative patents (number of patents filed)
$\log(y_t) = at + b$
$\log(y_t) = a\log(x_t) + b$
$\log(y_t) = a\log(z_t) + b$


Cylindrical
Blomgren 2000
Morrison 2002
TIAX 2002
Takeshita 2006
Kinoshita 2009
Kanamura 2017
Database
98th Percentile
Pouch
Morrison 2002
Database
All types / Non-specific
Powers 2002
Broussely 2003
Ikoma 2006
Yoshino 2014
98th Percentile
Prismatic
Morrison 2002
TIAX 2002
Database
Energy density (Wh/liter)
Date
0
100
200
300
400
500
600
700
800
1990
1995
2000
2005
2010
2015

Expansion of Battery Market (2021.01)

■ **Comparison of LIB capacity by Application**

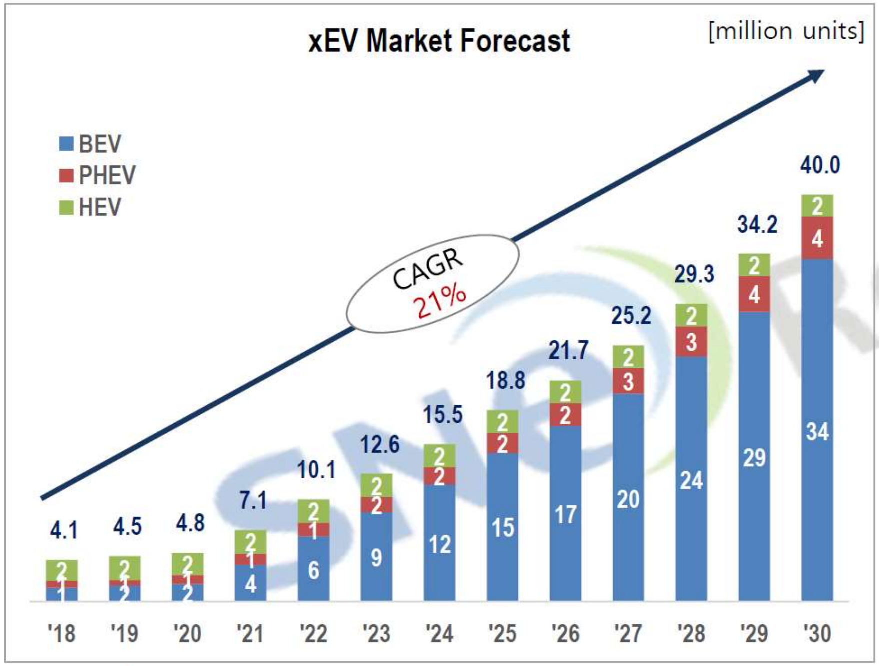
TESLA Model-S : 85~100kWh
TESLA Model-3 : 60~80kWh

	SmartPhone	Power Tool	E-bike	HEV	PHEV	BEV	E- BUS
Product							
LIB Average Capacity	**0.01 kWh** (4.2V * 3000 mAh = 12.6Wh)	**0.1 kWh** (6Ah * 18V=108Wh)	**0.5~1.0kWh** (36V * 15Ah=540Wh ,10S5P)	**1.1~ kWh**	**11.7~ kWh**	**33~100 kWh**	**80~200 kWh**
Capacity Ratio	**1**	**10**	**50**	**100**	**1,200**	**5,000**	**15,000**
2015 Sales	1,320,000,000 ea	63,600,000 ea	2,500,000 ea	1,690,000 ea	220,000 ea	320,000 ea	120,000 ea
	13.2 GWh	6.4 GWh	2.3 GWh	2.0 GWh	2.5 GWh	10.8 GWh	9.3 GWh
2019 Sales	1,200,000,000 ea	106,900,000 ea	6,500,000 ea	2,760,000 ea	530,000 ea	1,600,000 ea	77,000 ea
	12.0 GWh	10.7 GWh	6.6 GWh	3.3 GWh	6.6 GWh	90.0 GWh	15.0 GWh
2025F Sales	1,190,000,000 ea	200,000,000 ea	16,000,000 ea	3,440,000 ea	1,790,000 ea	14,700,000 ea	210,000 ea
	11.9 GWh	22.0 GWh	18.0 GWh	4.8 GWh	26.2 GWh	998.6 GWh	39.0 GWh

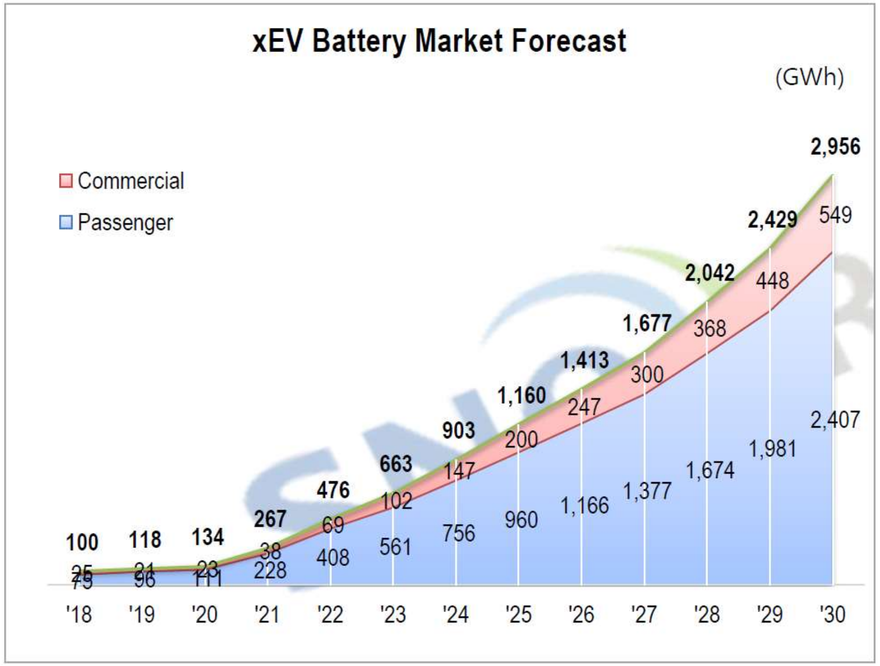
※ Including of Mild Hybrid

(Source : SNE Research)

Global xEV Market



※ Excluding Mild Hybrid

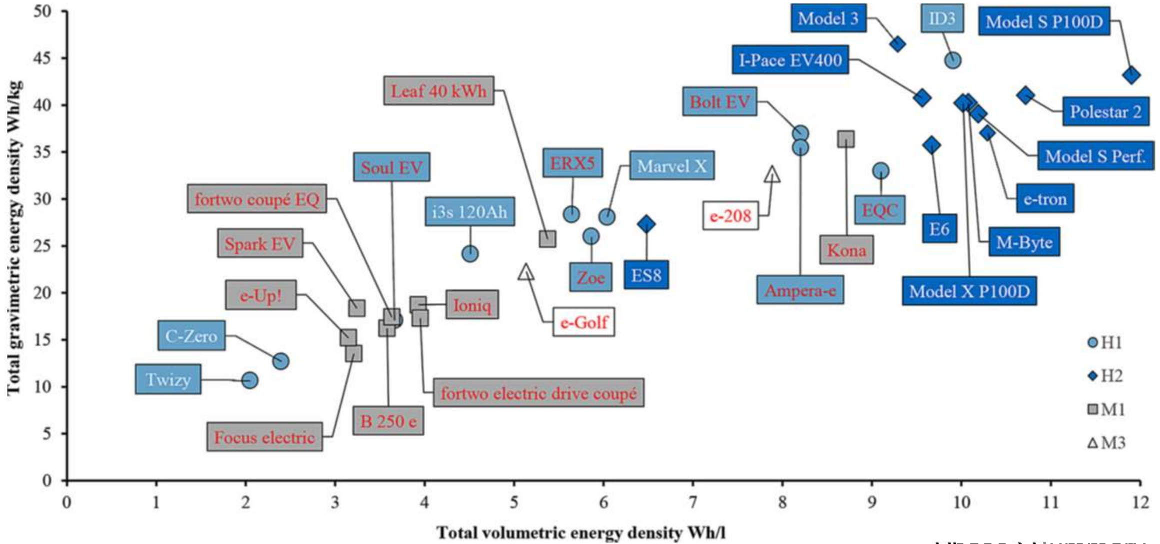


Source: <2020.2H> Global xEV market and Battery supply & demand outlook (~2030)

Direction of development of battery cells to meet the requirements of automakers

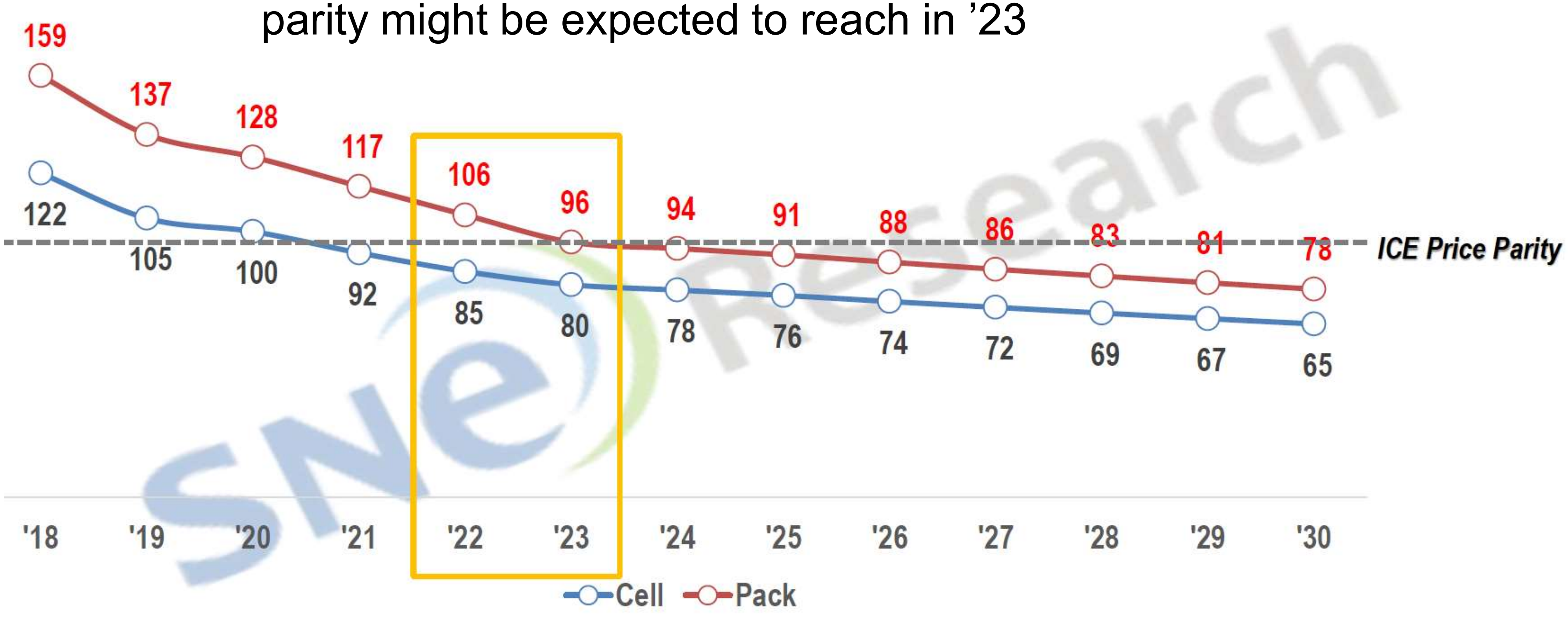
	2019	2021	2023	2025	Direction of Battery Cell Development
Energy Density↑	*260Wh/kg 620Wh/L*	*280Wh/kg 650Wh/L*	*310Wh/kg 750Wh/L*	*330Wh/kg 800Wh/L*	· *Cathode : high-loading, high-nickel(NCA, NCM, NCMA) Conductive materials(CNT)* · *Anode : Si-Anode, Conductive materials(CNT)*
Long Life Cycle	*800 Cycle*	*900 Cycle*	*1000 Cycle*	*1000 Cycle*	· *Minimize cell electrode structural deformation* · *Cathode: Conductive materials(CNT), LFP* · *Special electrolyte salts: $LiPO_2F_2$, LiDFOP, LiFSI*
Fast Charge	*2.0C*	*2.5C*	*3.0C*	*3.5C*	· *Cathode: Conductive materials(CNT)* · *Anode: Si-Anode(low loading), Conductive materials(CNT)* · *Special electrolyte salts: $LiPO_2F_2$, LiDFOP, LiFSI*
Cost Down	*110$/kWh*	*90$/kWh*	*80$/kWh*	*75$/kWh*	· *Cathode: high loading, high-Nickel(low Cobalt), LFP(Cobalt-free)*

	Cell Energy Density		
Target(Wh/kg)	2015	2020	2030
US DOE	150	200	
NEDO	150	200	500



Cost, Price and Profitability

– Battery prices for EV are down to 5 to 6 percent on average
– Cell : △ 5%, Pack: △ 6%
– Cell To Pack technology is expected to start expanding in ‘21
– ICE Price Parity: Based on pack price of 100$/kWh, year of parity might be expected to reach in ’23

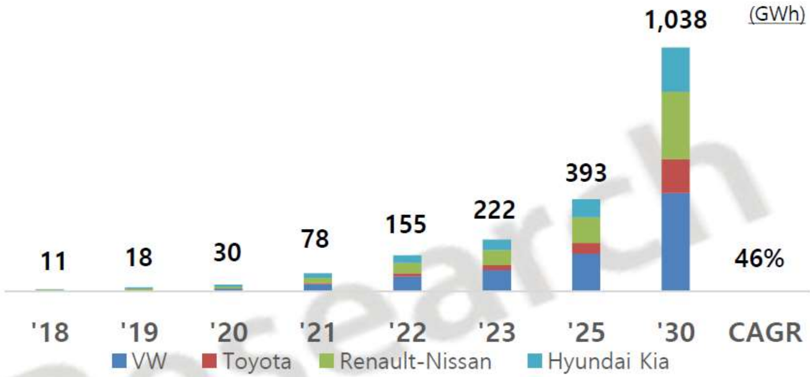


Competition of TESLA vs Traditional OEMs

– 2022Y: 155GWh vs 100GWh (60GWh, SNE Forecast)
– 2030Y: 1038GWh vs 3000GWh (274GWh, SNE Forecast)

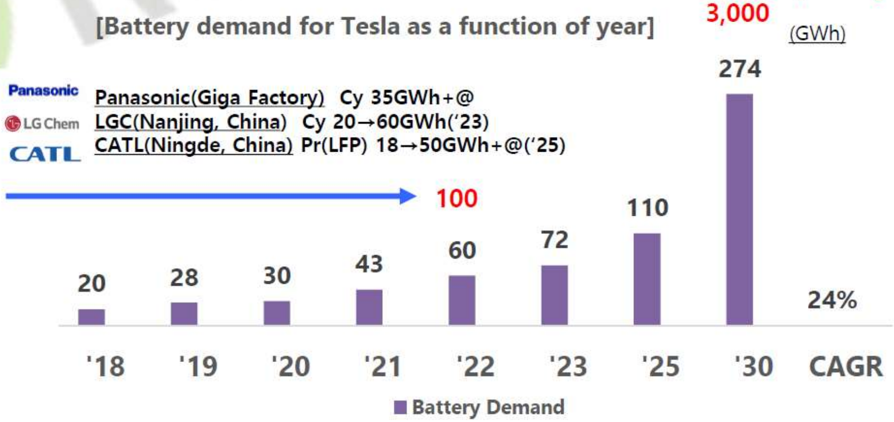
Volkswagen: LG Chem, SK innovation, Samsung SDI, CATL
Toyota: Panasonic, EV Energy, BYD
Renault Nissan: LG Chem, Envision AESC
Hyundai, Kia Motors: LG Chem, SK innovation

[Battery demand for 4 major Car OEM as a function of year]

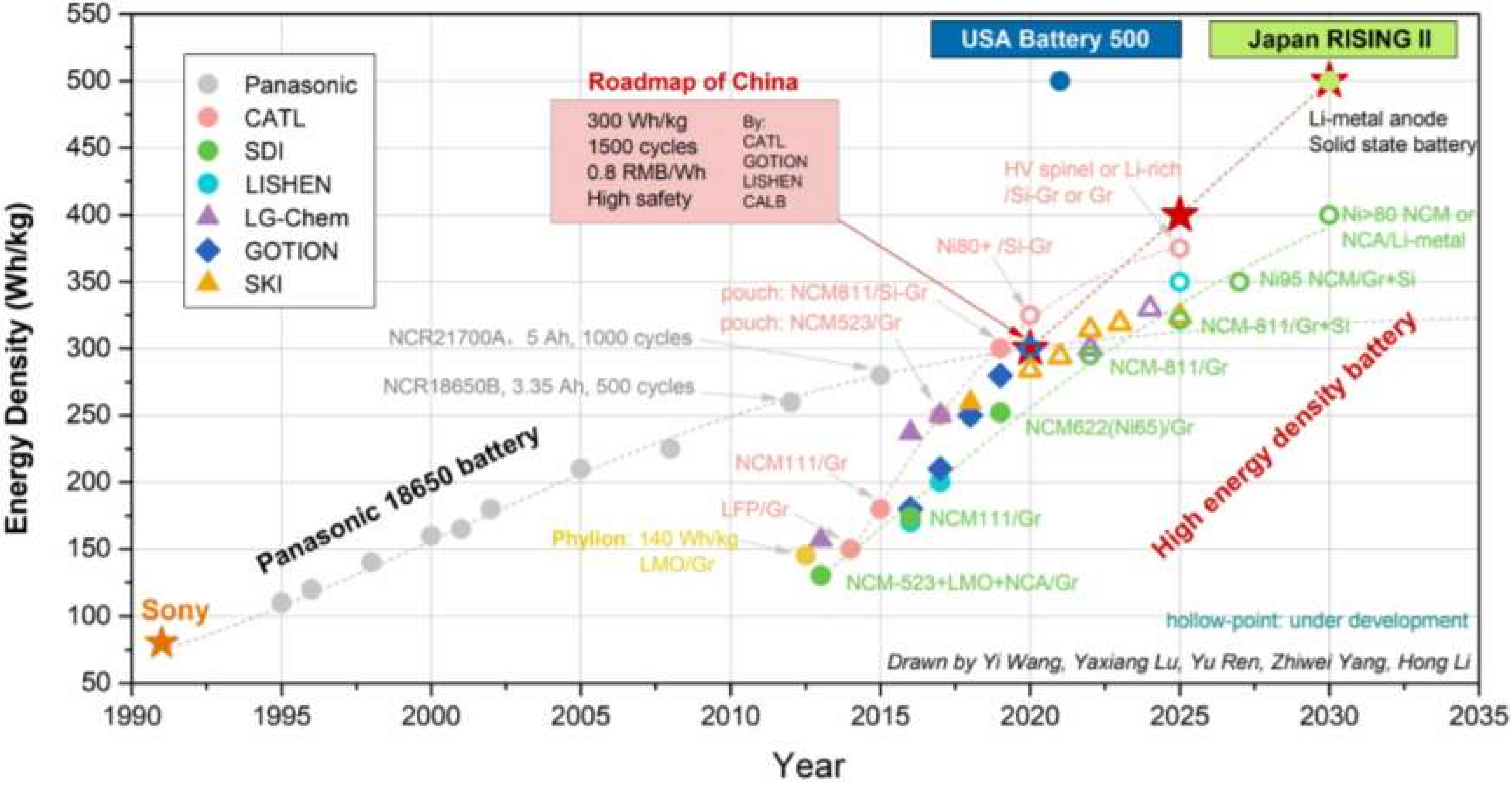


Tesla Plan (Battery Day)
3,000

[Battery demand for Tesla as a function of year]



BATTERY 2030+ Roadmap



Motor Technology and Cooling

- To meet customized automotive durability, weight, and cost requirements
- Maximum operating efficiency only in a narrow rpm range
  - Extending the efficient operating range and power density
  - Magnet arrangement and coil designs
- For larger speed ranges
  - Multi-speed transmissions: auxiliary power supply in typical hybrid vehicle
  - Single speed gear reduction: full traction power
- Closely coupled with DC power inverter hardware and software for optimized performance, efficiency and electro-magnetic emission resistance

Electric Motor Technology

– The motor is sized to provide maximum acceleration, grade ability and top speed
– Peak efficiency is only available in a small operating range
– Smaller motor is more efficient due to higher operating speed, but torque falls more rapidly as speed increases

	Units	Current	BEV	$PHEV_{20}$	FCEV	$PHEV_{40}$
Peak Power	kW	Varies	67	67	75	75
Continuous Power	kW	Varies	49	49	55	55
Max Torque	Nm	Varies	270	270	240	240
Max Efficiency	%	95	96	96	95	95
Specific Cost	$/kW	40	26	26	26	26
Specific Power	kW/kg	1.2	1.63	1.63	1.63	1.63
Specific Power	kW/l	3.2	4.8	3.3	3.3	3.3
Physical Volume	liters	Varies	14	14	23	23

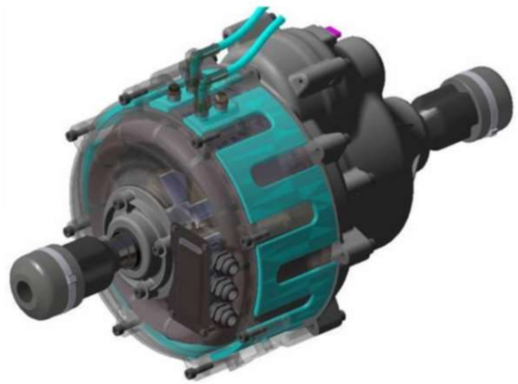
	Power density kW/kg		Motor Peak Power	Motor & Controller Mass	Motor Size		
	kW/kg	kW/l	kW	kg	Volume (l)	Diameter (mm)	Length (mm)
Gasoline Engine	0.59	0.9	75.0	127.1	79.5		
EV Drive Motor 2015-2020 *	1.32	4.80	75.0	56.9	15.6	280.0	253.0
Improvements from Gasoline Engine to Electric Motor	123%	409%		-55%	-80%		

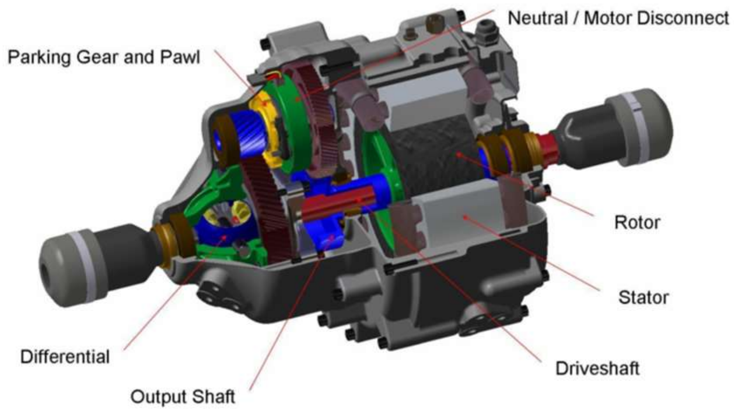
Year	Power Density (kW/Kg)
2010	1.06
2015	1.2
2020	1.4

Motor and Transmission Gear Ratio

- Vehicle acceleration performance (0-100 km/h): peak power
- 10% grade climb at 100 km/h: continuous power
- Vehicle top speed (km/h): continuous power
- Motor efficiency (%)

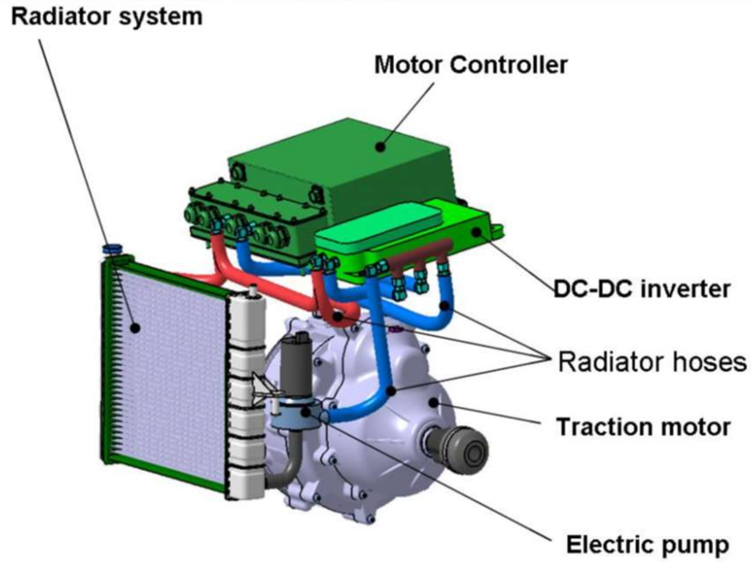
acceleration							NEDC	grade test
gear ratio	total ratio	acceleration	top speed	power motor	torque	speed	motor bidirectional efficiency	10% 100km/h
		0-100km/h	km/h	peak/continous	Nm	rpm	%	cont. kW motor
1	3.9	14.8	197	67 / 67	220 / 95	6760	89.23	49
1.2	4.68	12.8	183	67 / 55	220 / 70	7550	89.47	49
1.4	5.46	11.6	158	67 / 37	220 / 46	7600	89.08	49
1.5	5.85	11.2	148	67 / 31	220 / 39	7620	88.88	49
1.6	6.24	10.8	138	67 / 26	220 / 33	7630	88.73	49
1.8	7.02	10.4	123	67 / 20	220 / 24	7650	87.84	49

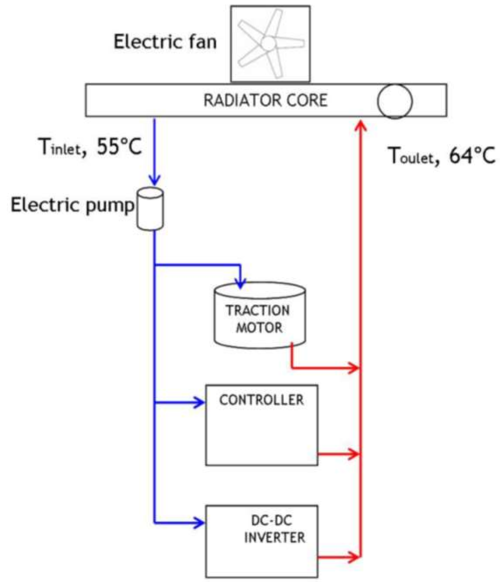


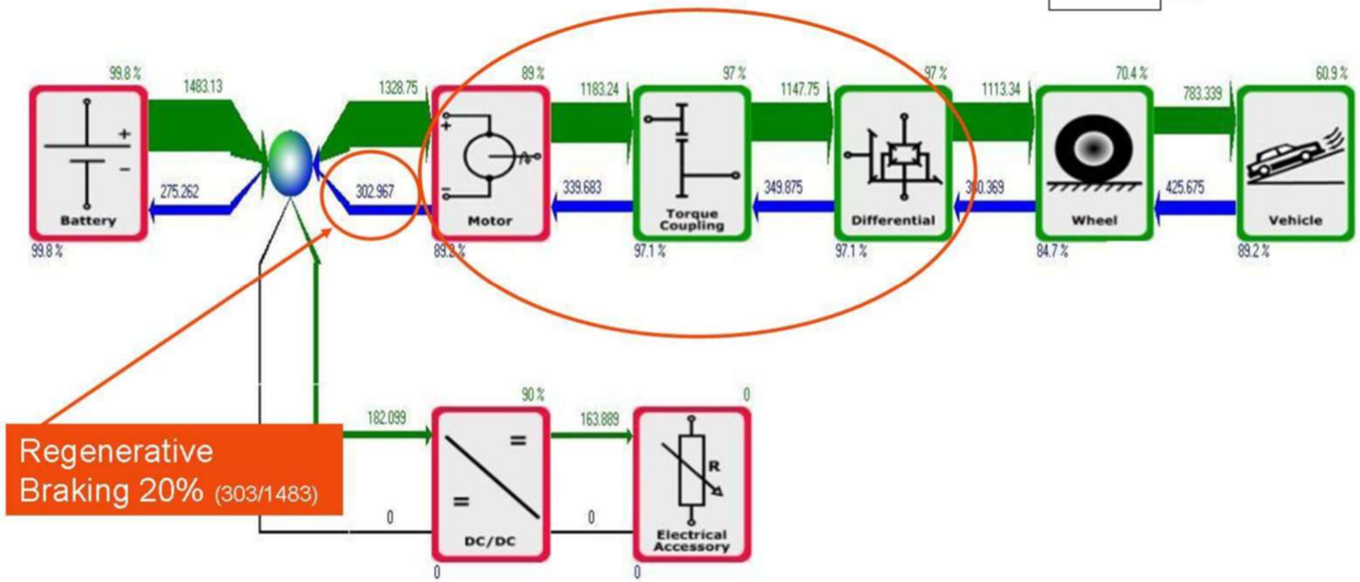


Mass: 68 Kg

Cooling System, Energy Balance

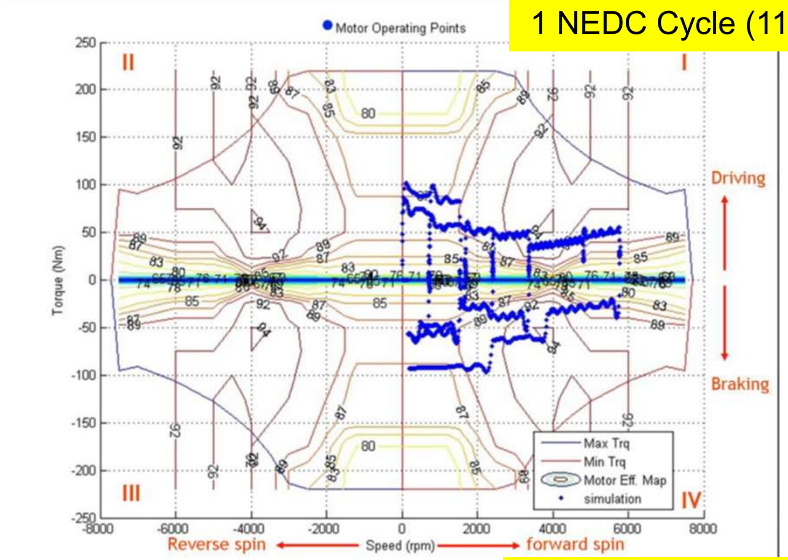




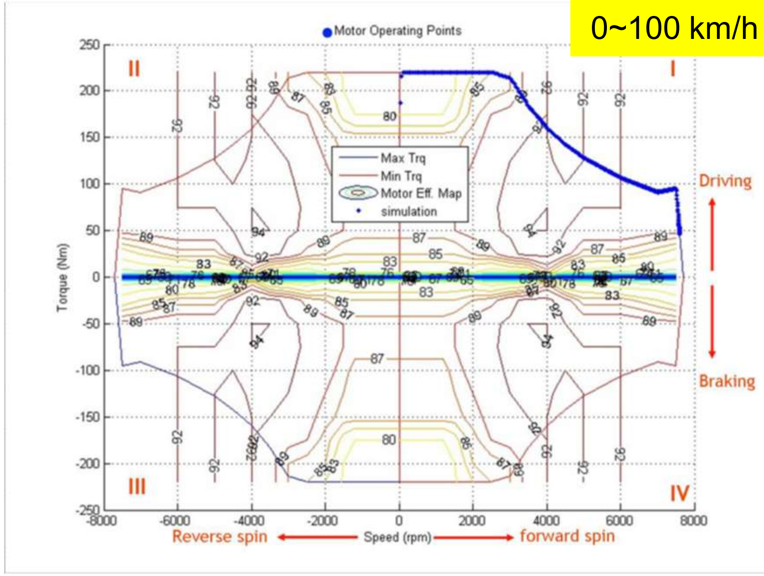


Motor Torque vs. RPM Curves

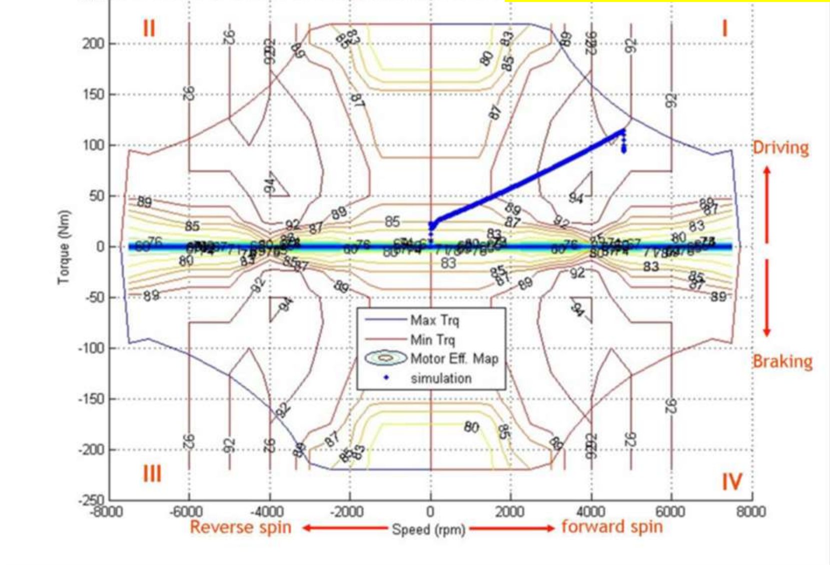
1 NEDC Cycle (11 km)

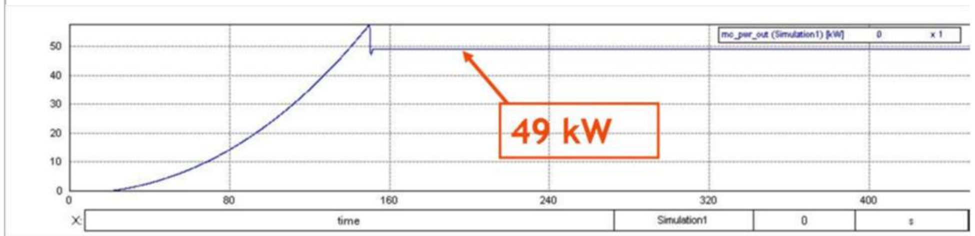


0~100 km/h



10% grade @100 km/h





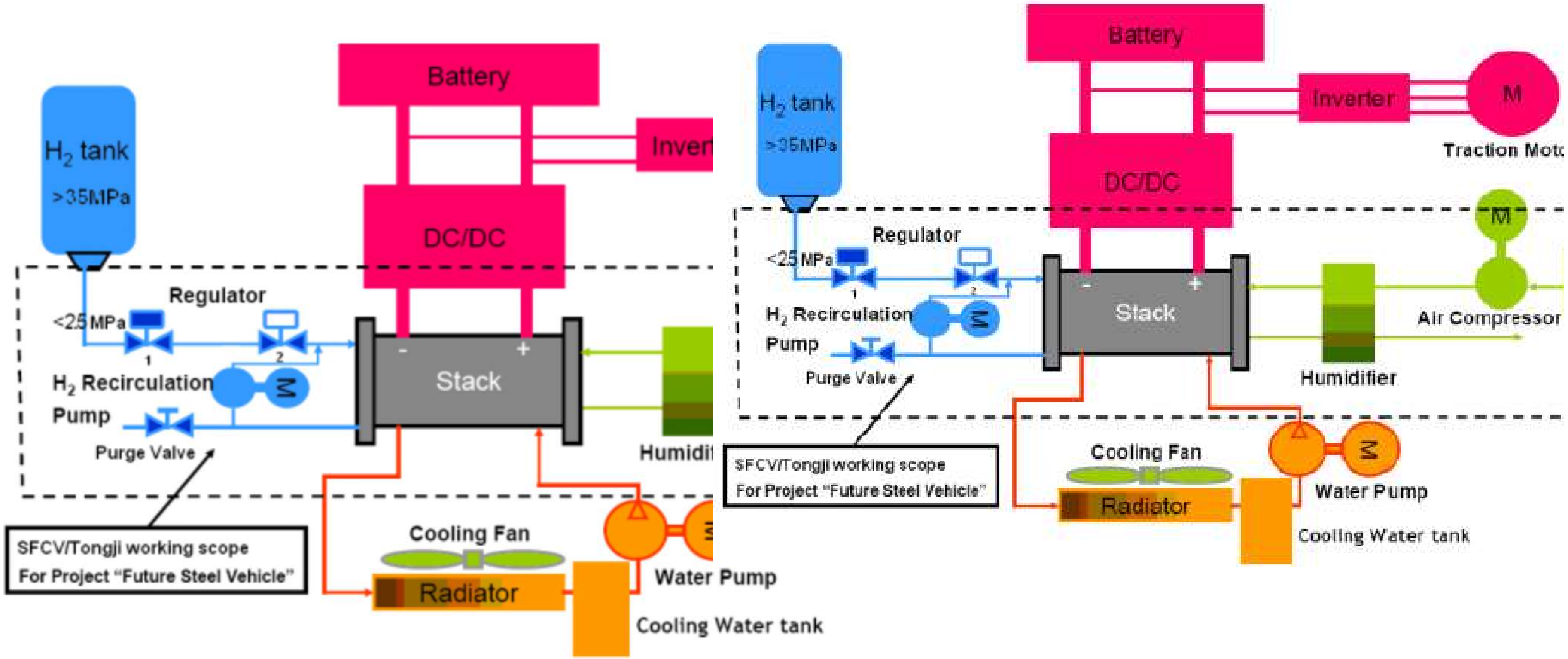
Fuel Cell Technology

- Proton Exchange Membrane or Polymer Electrolyte Membrane (PEM) fuel cell
- five types depending on the allowable working conditions (pressure and temperature) or the membrane materials

Types	Advantages	Disadvantages	Application
HT-PEMFC (90-120°C)	More tolerance to CO; Low requirement on thermal management system	Difficult fabrication process; Corrosion of metal stack components	Laboratory testing only
LT-PEMFC (<90°C)	Rapid start-up; High current density	High requirement on thermal management system	Prototype level, Highly developed
Self-breathing	No air compressor; High system efficiency; Low cost; Simple structure	Low power output; Less applications in transportation	Prototype level only with small power output (<10kW)
High Pressure Fuel Cell (>0.2MPa)	High power density; Easy cold start	More parasitic losses; High requirement on sealing	Prototype level
Low Pressure Fuel Cell (<0.2MPa)	Low requirement on sealing;Simple structure	Low power density and efficiency	Prototype level

Direct hydrogen PEM fuel system

- Include: low pressure (<2.5 MPa) hydrogen delivery, air supply, fuel cell stack, compressor and humidifier
- Exclude: heat rejection unit, hydrogen storage and DC electric power inverter



FSV Recommendation

Fuel Cell Technology Assessment

		Status 2008	Prediction 2015-2020	Selection FSV
Dominating Technology		PEM	PEM	PEM
Power Output (net)	kW	40 - 100	50 - 170	65
Efficiency	%	45 - 56	50 - 62	50 - 62
Power Density	kW/kg	0.8 - 1.9	~2.0	2
Cost [$USD]	$ USD/ kW	1,500-2,900	~100 - 200	155

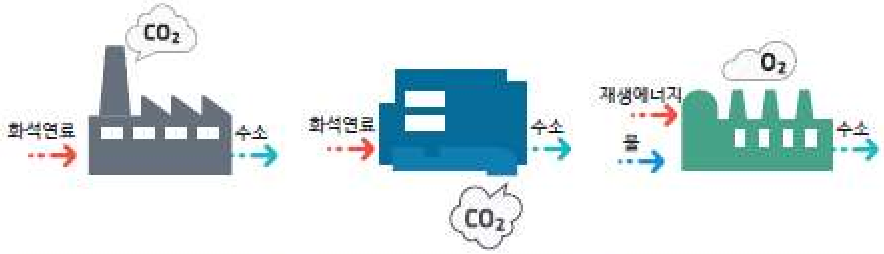
Hydrogen Storage Technology Assessment

		Status 2008	Prediction 2015-2020	Selection FSV
Dominating Technology		Compressed Gas		Compressed
Pressure	MPa	35	50 - 70	70
Tank Material	Carbon Composite	Aluminum Liner	Plastic Liner	Plastic Liner
H_20 Volume Capacity	Liters	80 - 220	70 - 150	95
Hydrogen Capacity (net)	kg	1.7 - 5.0	1.6 - 5.4	3.4

Future Steel Vehicle Concept

Without Cooling System	Capacity (net)	Weight [kg]	Volume [Liters]	Cost [$ USD]
Fuel Cell Engine	65 kW	92	67	$10,081
Hydrogen Storage	3.4 kg	87	120	$7,919

수소 종류 및 특징



		그레이 수소(부생수소)	블루 수소(추출수소)	그린 수소(수전해수소)
생산방식		• 천연가스 등 화석연료 개질 (Reforming)수소생산으로 CO_2 발생	• 발포된 CO_2를 포집/저장	• 재생에너지 기반으로 CO_2 미발생 (궁극적인 지향점)
장 점		• 별도의 설비가 필요 없어 생산가격 저렴	• 기존에 구축된 천연가스 공급망과 연계가능	• CO_2 등 부산물이 없어 친환경적
단 점		• 석유화학 공정에서 발생하므로 추가공급 한계 • CO_2 등 부산물 발생	• 생산과정에서 CO_2 등 부산물 발생	• 현재 수전해 기술개발 및 실증·상용화 한계
생산비용 전망 (단위:원)	2018년	1,500~2,000	2,700~5,100	9,000~10,000
	2022년	1,500~2,000	2,600~4,800	7,000~8,000
	2030년	1,500~2,000	2,500~4,300	3,000
	2050년	1,500~2,000	2,400~3,900	2,000

출처: POSCO, 국회예산정책처, 에너지경제연구원

- 한국은 다른 국가들 보다 수전해 수소 설비 관련 기술력도 열위에 있는 상황이라 비용적 문제를 해결하고 경제성을 갖추기까지는 시간이 걸릴 것으로 예상
- 에너지 전환을 위해 꼭 필요한 기술인 수소환원제철과 이산화탄소 포집 및 활용(CCU) 기술 등도 아직까지는 상용화에 한계가 존재
- 수소환원제철은 기술개발의 성공과 수소의 안정적 공급기반 구축이 핵심이나, 이제 기반 구축을 막 시작하는 단계로 기술의 실질적 활용은 요원한 상황
- CCU 기술의 경우 경제성을 확보한 포집제 개발 및 포집 공정의 상용화에 아직 성공하지 못하고 있음

생산방식 별 수소에너지 종류 (1)

- 그레이 수소
  - 천연가스에서 추출한 추출수소
    - 국내에선 전국에 천연가스 배관망이 이미 구축돼 있기 때문에 수소추출기만 설치한다면 추출수소를 활용
    - 국내 수소추출기 기업으로는 제이엔케이히터(7,500 -1.06%)가 있긴 하지만 대부분은 일본 기업들
  - 정유공장 나프타 분해시 생산되는 부생수소
    - 대부분 울산, 여수, 대산 등 산업단지에서 생산, 연간 약 243만톤
    - 주요 생산업체로는 시장 점유율 50%를 차지하고 있는 ㈜덕양 외에 SPG산업/케미칼, 에어리퀴드코리아, 풍국주정의 자회사인 에스디지(SDG)
- 블루수소
  - 천연가스에서 추출수소 생산시 나오는 이산화탄소를 포집해 분리, 저장하는 방식(CCS•Carbon Capture and Storage)으로 생산한 수소
- 청록수소
  - 블루수소와 그린수소의 중간 단계, 메탄을 열분해 해서 생산하는 수소

생산방식 별 수소에너지 종류 (2)

- 그린수소
  - 전해질에 재생에너지 전력을 공급해 물을 수소와 산소로 분해하는 '수전해 방식'으로 생산한 수소
  - CO2 배출량이 전혀 없는 가장 이상적인 수소에너지이지만 그레이, 블루 수소에 비해 생산 가격이 5~6배 이상 비싸기 때문에 당장 상용화까지는 상당 시간이 걸릴 전망
  - 수전해 설비: 14MW(2019년)→1600MW(2025년)로 급증할 것으로 전망 (시장조사업체 IHS)
  - 그린수소의 핵심은 원가: 현재 전세계 그린수소 가격은 Kg당 2.5~4.5달러 수준으로 2030년에는 평균 2달러까지 하락하며 경제성을 갖출 것이란 전망

생산방식 별 수소에너지 종류 (3)

- 전해질 종류에 따라 알카라인(AEC), 고분자 전해질막(PEM), 고체산화물(SOEC)로 구분
  - 알카라인(AEC): 가장 보편화된 방식으로 기술력이 입증됐으나 중국 업체들이 이미 장악한 상황, 독성물질을 배출한다는 약점
    - 노르웨이 NEL, 일본의 아사이카세이, 국내에는 이엠솔류션
  - 고분자 전해질막(PEM): 전류 밀도가 높아 에너지 효율이 높고 소형화가 가능하다는 장점, 다만 귀금속 촉매를 사용하기 때문에 저가의 막과 촉매 개발이 필수적, 풍력 태양광 등 재생에너지는 기후변화로 인해 출력 변동성이 심하기 때문에 PEM 방식이 점차 대세가 될 것이란 의견이 우세
    - 커민스의 자회사인 캐나다 하이드로제닉스, 영국 ITM파워, 독일 지멘스 등, 국내 기업으로는 엘켐텍이 도전
  - 고체산화물(SOEC): 700°C이상 고온에서 작동하는 단점이 있으며 현재 기술은 기초적인 연구단계

운송 및 저장 단계

- 전기로 수소를 생산해 다시 전력원으로 쓰는 게 낭비
- 잉여전력을 수소로 전환해 보관하고 장거리 운송을 한면 매력
- 전력망 없이도 재생에너지를 오래 보관, 장거리로 이동하는데 효율적

- 수소의 운송저장방식
  - 고압기체 저장방식: 파이프라인과 튜브트레일러를 통해 운송
  - 기체 상태의 수소를 액화하는 액화수소 저장방식
    - 고압수소 대비 4~5배 이상의 저장 효율성
    - 액화과정에서 24~45% 에너지 손실
    - 효성+린데그룹(미국): 2023년부터 액화수소 생산과 유통
  - 액상유기수소화물(LOHC) 방식
    - 액상수소운반체(L)를 이용해 수소를 저장하고 운송
    - (예) 수소를 톨루엔에 결합해 메틸시클로헥산으로 전환해 운송한 뒤 다시 역 반응을 통해 수소를 추출하는 방식
    - 일본 치요다 미쓰이 미쓰비시 니폰유센 등이 브루나이에서 실증을 시작
  - 액상유기수소화물과 비슷한 암모니아 방식

소비단계

- 모빌리티: 수소차
  - 전기차 대비 가격 경쟁력을 감안했을 때 승용차 보다는 장거리 운행을 하는 버스 트럭 같은 상용차 시장이 핵심
  - (국내) 2022년까지 수소버스 2000대를 보급한다는 계획
  - (중국) 2030년까지 수소 차량 100만대를 목표
  - 수소모빌리티에선 도요타 현대차 다임러 니콜라 등이 경쟁
- 연료전지
  - 발전용, 가정•건물용, 수송용으로 활용
  - 유럽은 수소를 대형 발전소의 에너지원으로 보기 보단 건물용 난방 수단으로 보고 있음
  - 한국 일본 등 재생에너지 발전량이 부족한 국가에서는 연료전지 발전이 필수적, 탄소중립을 달성하기 위해서는 해외에서 재생에너지를 수입해야 하는데 이때 태양광 풍력을 전력으로 저장하는 방법으로 수소 연료전지가 유용

연료전지 종류: 전해질

구분	인산형 연료전지 (PAFC)	용융탄산염 (MCFC)	고체산화물 연료전지 (SOFC)	고분자전해질 연료전지 (PEMFC)
전해질	인산염	용융탄산염	고체산화물	고분자막
작동온도	150~250℃	650℃	600~900℃	50~100℃
주 촉매	백금	Perovskite	니켈	백금
전기효율	40~50%	45~60%	50~60%	<40%
복합효율	90%	88%	-	-
주용도	발전용 가정/건물용	발전용 가정/건물용	발전용 가정/건물용	수송용, 휴대용
주요기업	두산퓨얼셀	퓨얼셀에너지 한국퓨얼셀	블룸에너지, 세레스파워 블룸SK퓨얼셀	발라드파워, 파워셀 플러그파워 두산퓨얼셀, 에스퓨얼셀