26th annual INCOSE international symposium

Edinburgh, UK

July 18 - 21, 2016

Learning Systems Engineering Lessons from an Electric Vehicle Development

Gerhard Swart

nnual INCOSE
ternational symposium
inburgh, UK
18 - 21, 2016

www.incose.org/symp2016

Context – 2005 start-up

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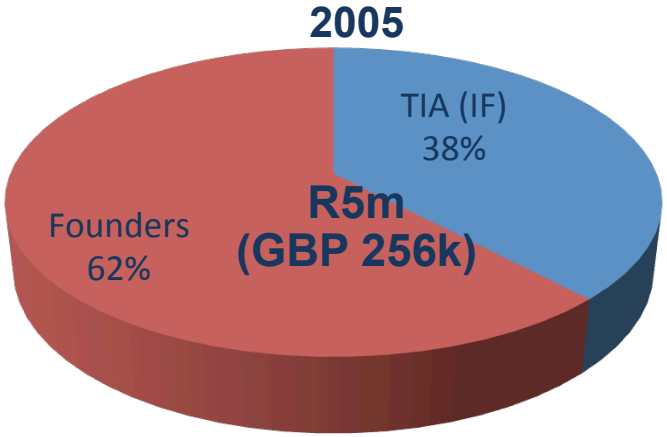
Disruptive opportunity for SA:

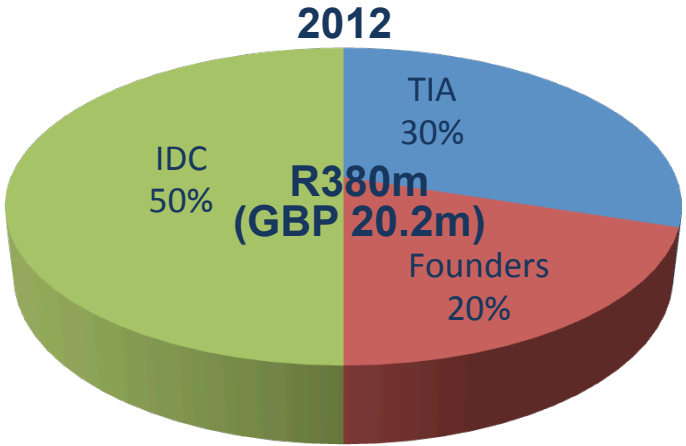
- Peak Oil, global warming, energy awareness
- Li-ion Battery technology becoming mature
- Automotive incumbents slow to adapt
- Strong SA automotive manufacturing (7 OEMs)
- Strong Systems Engineering community (mostly defence)

"To establish and lead the Electric Vehicle industry in South Africa and then expand globally."

Context – very modest funding

- 4 founders growing to 105
- Business control diluted by government agency investors





- Company closed June 2012 after investors decided business risk too high
- See ***Innovation Lessons learned from the Joule EV Development*** (paper presented IAMOT conference, June 2015)

The Joule EV

5-seater C-segment city vehicle
0-60km/h in less than 5s
Max Speed 135km/h
Designed for NCAP 5-star

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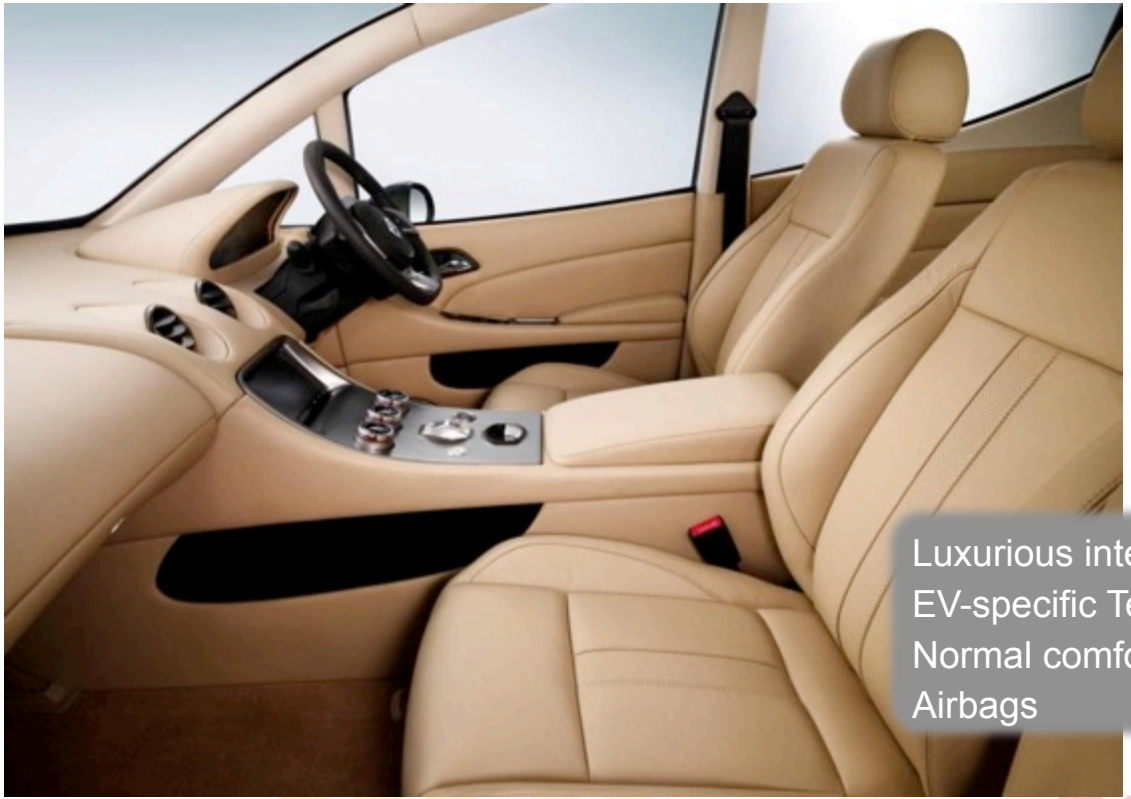
The Joule EV



Luxurious interior
EV-specific Telematics
Normal comfort features
Airbags

New core technologies

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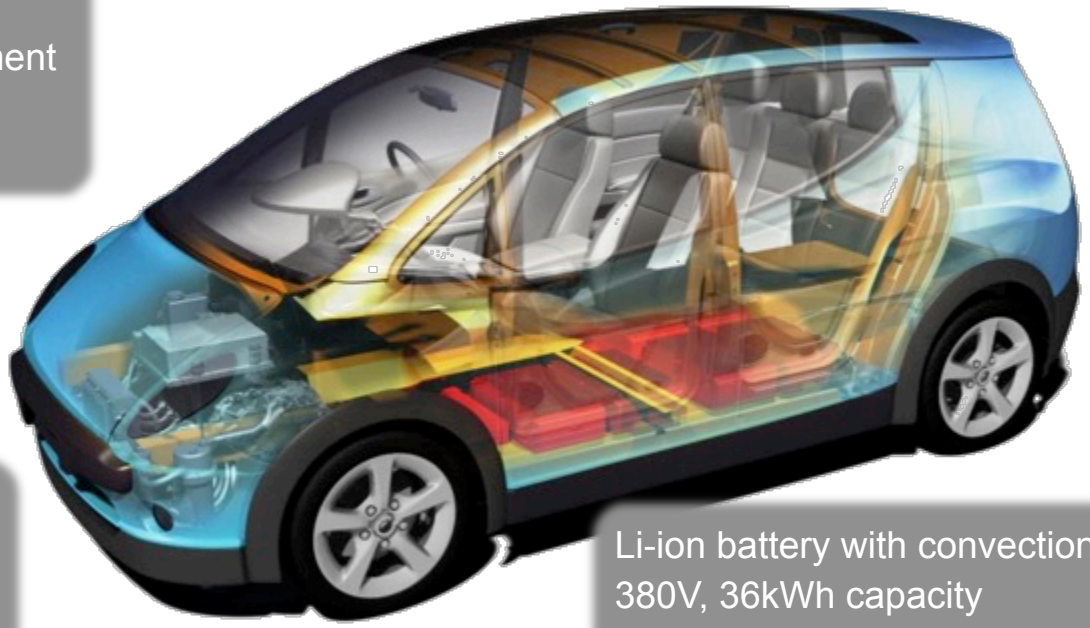
75kW peak STM motor
Large luggage compartment
Optional PV panel roof
On-board charger

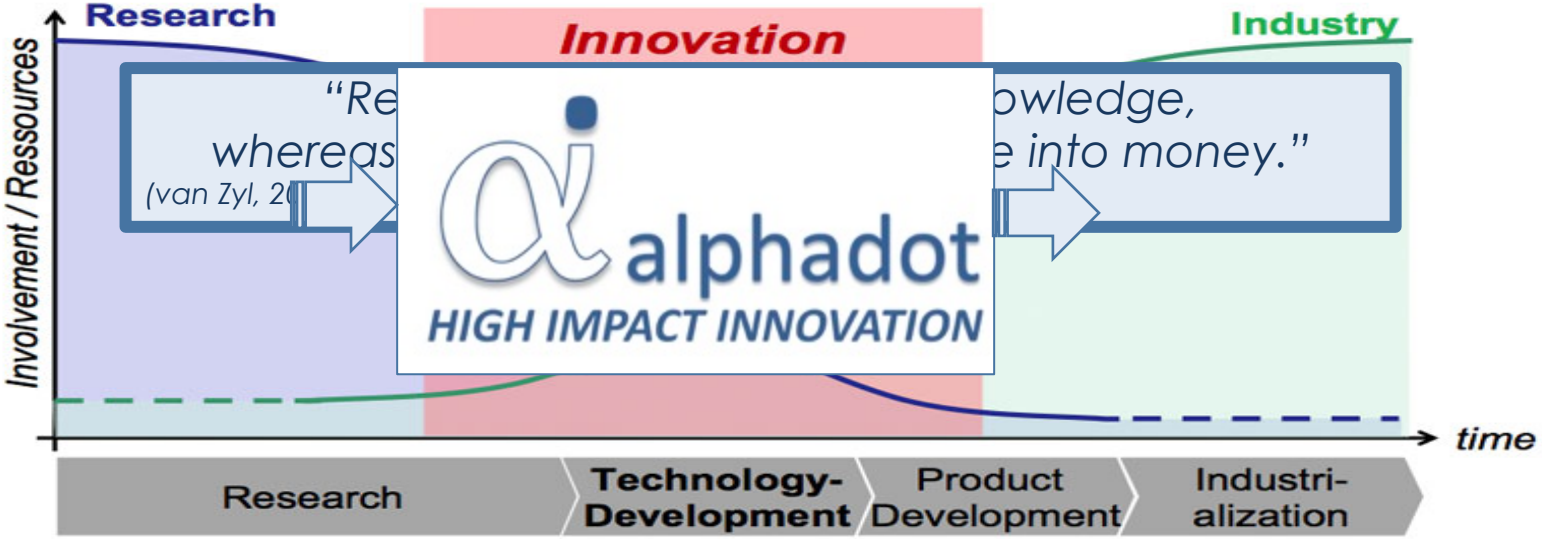


Integrated SW control
Infotainment and telematics
Internet-enabled apps
User customisation

Li-ion battery with convection cooling
380V, 36kWh capacity
Swappable from below
Range ~230km (NEDC)


ROAD TESTS
car
WORLD EXCLUSIVE
SA'S ELECTRIC CAR
WE'VE DRIVEN IT. IT'S GOOD. NOW WHAT?
BMW'S RADICAL FUTURE
BMW 6 SERIES

Context - The innovation chasm



- Academic freedom
- Limited control
- Freely creative
- Research partners
- IP - focussed

- Formal processes
- Project control
- Targeted outcomes
- Industry Partners
- Product-focussed

- Business processes
- Product control
- Industry processes
- Supply chain
- Customer focussed

This paper

- Are Electric Vehicles different?
  - Cost & pricing models
  - Mechanical and Electrical architecture
- How are cars traditionally developed?
- Joule Development processes
  - Joule initial tailored SA process
  - Hybridised SA/Automotive process
- Conclusion

Are EV's different?

Automotive Engineer: *Electronics is added to a car to make it safer and more convenient*

Elon Musk: *Model S is not a car but a 'sophisticated computer on wheels'*

EV Pricing is different

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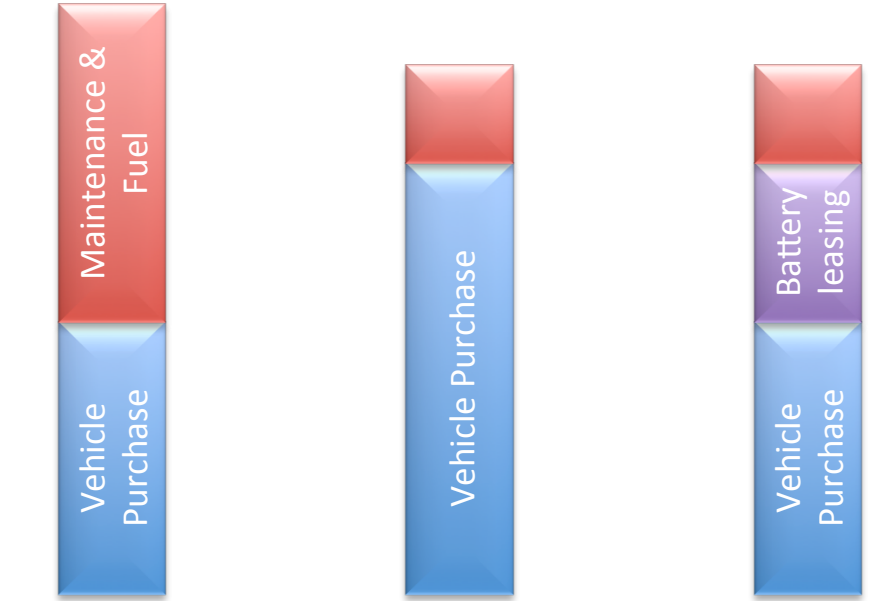
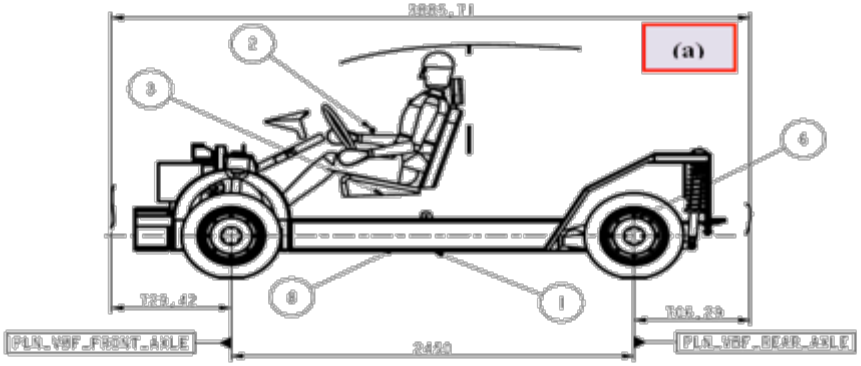
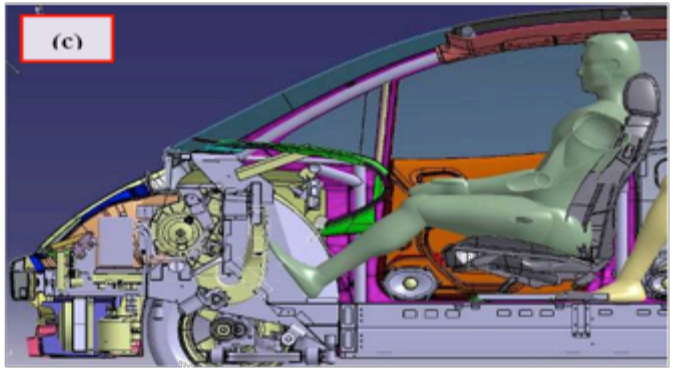


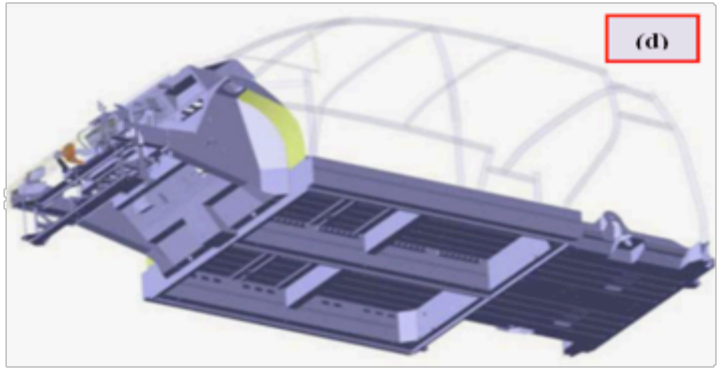
- New business models
- Different cost drivers

=>Clean sheet preferred

New mechanical architecture







Battery is central component

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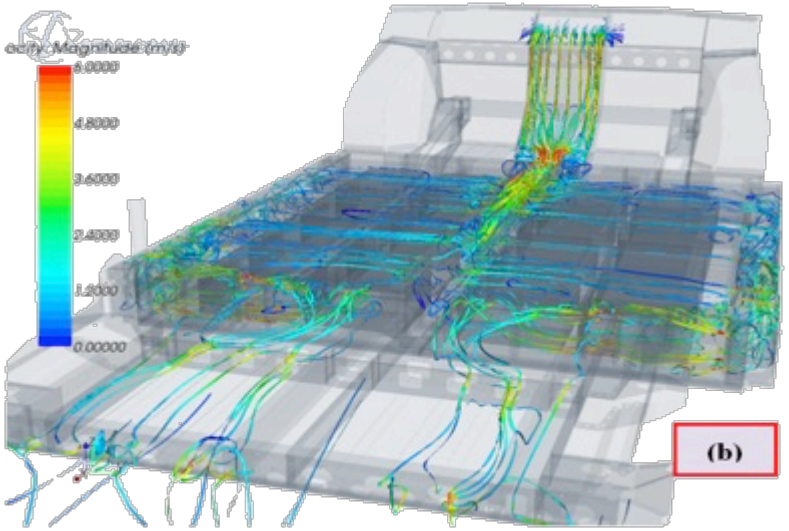
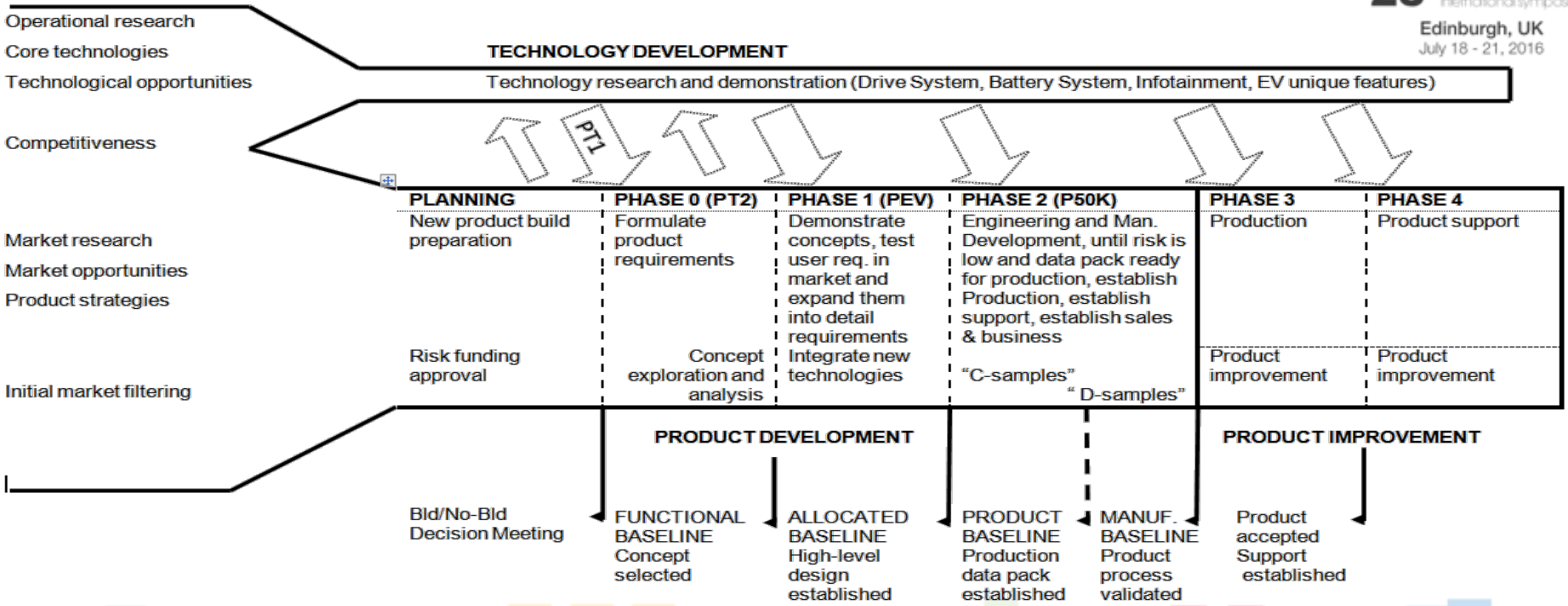
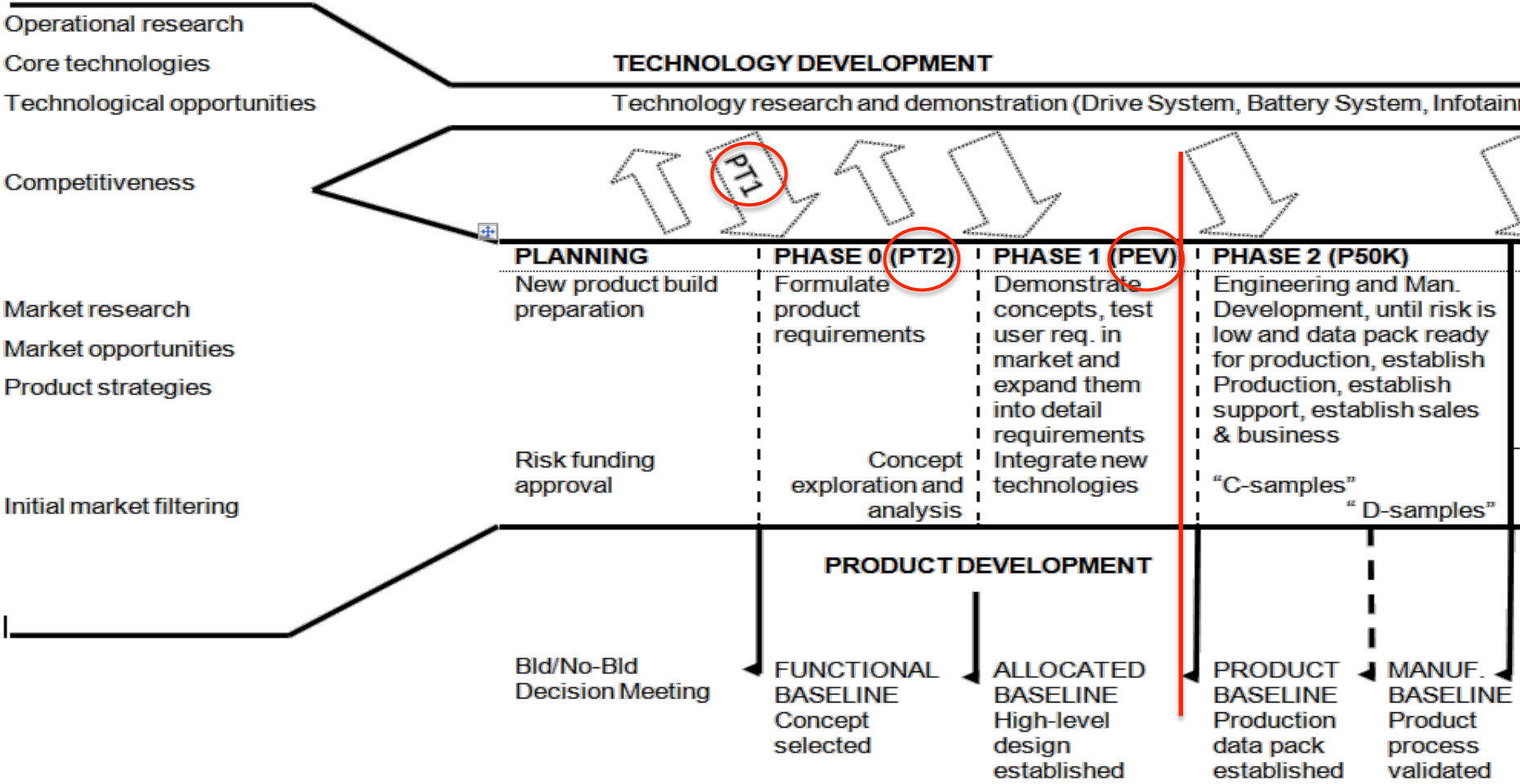
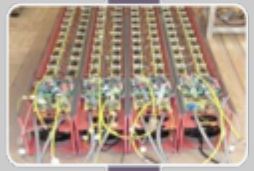


Initial top-down process



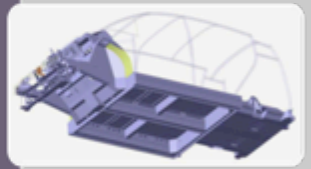

Operational research
Core technologies
Technological opportunities
TECHNOLOGY DEVELOPMENT
Technology research and demonstration (Drive System, Battery System, Infotain
Competitiveness
PT1
PLANNING
PHASE 0 (PT2)
PHASE 1 (PEV)
PHASE 2 (P50K)
New product build preparation
Formulate product requirements
Demonstrate concepts, test user req. in market and expand them into detail requirements
Integrate new technologies
Engineering and Man. Development, until risk is low and data pack ready for production, establish Production, establish support, establish sales & business
Market research
Market opportunities
Product strategies
Risk funding approval
Concept exploration and analysis
"C-samples"
" D-samples"
Initial market filtering
PRODUCT DEVELOPMENT
Bld/No-Bld Decision Meeting
FUNCTIONAL BASELINE Concept selected
ALLOCATED BASELINE High-level design established
PRODUCT BASELINE Production data pack established
MANUF. BASELINE Product process validated

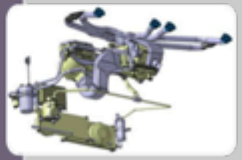
PT1



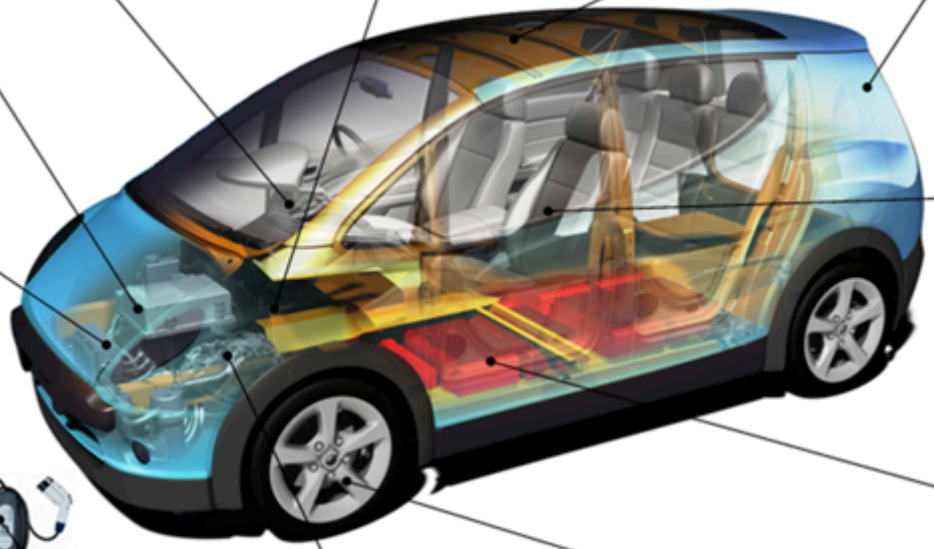
PT2

PEV





Joule links to industry



Electric Motor*

New: High performance & efficiency, automotive volumes and quality.
Benefits: Technology development capacity, testing facilities, new engineering skills, manufacturing industry, export possibility, mineral beneficiation (Rare-earths, Cu).
Spin-offs: Electric buses, rail, defence/airport vehicles, mining & aerospace, wind generators.

SAVCIO · Stellenbosch University · Oceantech Energy · SABS · east london idz · UQM Technologies · unito.it

Information & Telematics Systems*

New: Vehicle integrated, web integration, remote diagnostics, CRM, new technology.
Benefits: Technology development capacity, new engineering skills, manufacturing industry, ICT industry growth.
Spin-offs: ITS on SA roads, integration with cell-phone networks, traffic safety systems, geo-fencing, fleet management systems.

mX Telematics · better place · its South Africa · Continental

Air Conditioning & Ventilation

New: Electric compressor, high efficiency.
Benefits: New engineering, simulation & analysis skills, expanded manufacturing capacity.
Spin-offs: Stationary air-conditioning systems.

BEHR · PI Engineering · Smiths

Solar Panel

New: Specific form factor, flexible, high efficiency, low cost, automotive volumes, reliability and quality.
Benefits: manufacturing industry, links to other sustainable programs.
Spin-offs: Eskom solar power projects, solar charging stations, rural power.

University of Johannesburg · sasol

Body, Trim & Glass

New: Joule-specific parts and some carry-over, light-weighting designs, development, testing & manufacture, EV crash safety, recycling.
Benefits: New research skills, tooling skills, steel use, artisans, expanded or new manufacturing.
Spin-offs: Capacity for other manufacturing.

SABS · Lapple · CSIR · PG Group · EDAG · Vulcan · Hella · Intrimbi

Power Electronics*

New: Motor controller, HV safety circuits, DC/DC converters, High efficiency, low cost, automotive volumes and quality.
Benefits: Technology development capacity, testing facilities, new engineering skills, manufacturing industry.
Spin-offs: Electric buses, defence, airport vehicles, underground vehicles, other automotive, Eskom, industrial solar/wind power.

MLT Drives · Brusa · SABS · Semikron · Magna Electronics

Seats, Interior and Cockpit

New: Joule-specific parts and some carry-over, sustainable materials development, testing & manufacture, recycling.
Benefits: New research & design styling skills, tooling skills, engineering, agri-processing, expanded or new manufacturing.
Spin-offs: Bio materials in furniture, buildings and other vehicles.

SABS · faurecia · CSIR · EDAG · Intrimbi · Johnson Controls

Battery System*

New: Cell technology, High efficiency, low cost, BMS, automotive volumes and quality , assembly
Benefits: Technology development capacity, testing facilities, new engineering skills, manufacturing industry, export possibility, mineral beneficiation (Mn, Al, Cu).
Spin-offs: Electric buses, defence vehicles, airport/underground vehicles, other automotive, Eskom, solar and wind energy storage.

EiG · HySA Public Awareness · TATA · IDC · SABS · Nelson Mandela Metropolitan University · CSIR · University of the Western Cape · east london idz

Whole Vehicle

New: SA Vehicle Development, EV-specific testing, automotive styling, body shop, paint plant and assembly plant.
Benefits: New engineering skills, more sustainable development & testing capacity, EV standards, manufacturing, sustainable industry, SA Brand.
Spin-offs: Expanded tertiary training, related industries, parts re-use in other vehicles.

SABS · east london idz · Arplus · IDIADA · P3 · EDAG · MIRA · Superformance

Off-Board Charging*

New: Chargers, power billing, infrastructure.
Benefits: New businesses, local installation work, new engineering and ICT skills, franchise opportunities, testing and standards creation.
Spin-offs: Sustainable filling (charging) stations, less refineries needed.

SABS · GE Energy · Siemens · better place · sasol · Eskom

Electronics, Wiring & Software*

New: New technologies added, high-voltage wiring systems, new capacity.
Benefits: Technology development, new engineering skills, increased manufacturing, improved competiveness for automotive supply.
Spin-offs: Airport, defence and mining vehicles, wind/power projects, industrial HV equipment.

TE · Beltronix · Pi Shurlok · MTA · Optimum

Brakes, Wheels, Suspension & Steering

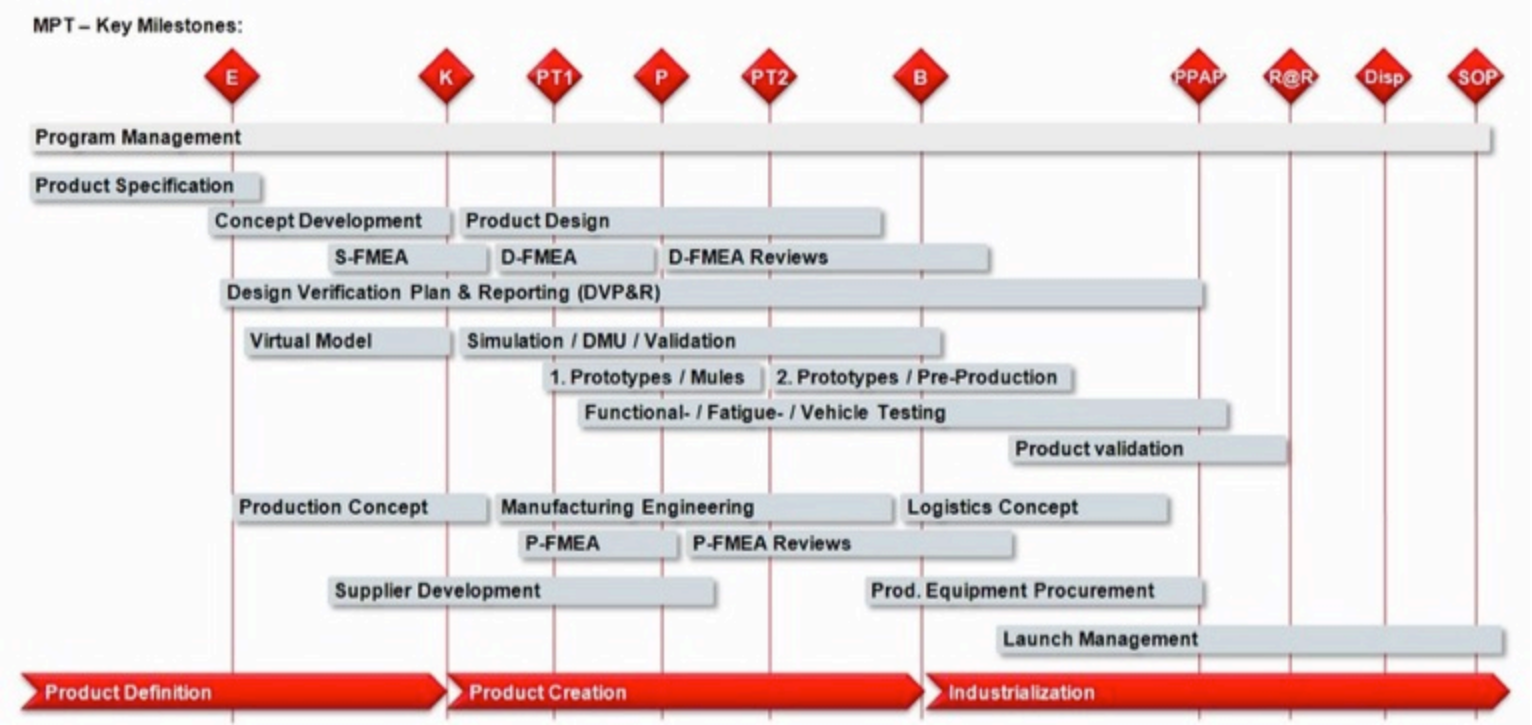
New: Mostly carry-over parts, unique Joule application, regenerative compatible brakes.
Benefits: Expanded manufacturing capacity, engineering & analysis skills, improved brake testing facilities.
Spin-offs: Use in other EV's.

SABS · Benteler · ZF · Continental · EDAG

* These systems are new to EV's and require significant new parts development by OE.

OPTIMAL ENERGY
engineering mobility

Evolutionary process



Ref: Magna Steyr, 2015, https://www.ecs.steyr.com/Product-Development-Process.1329.0.html?&L=1

Parts-centric process

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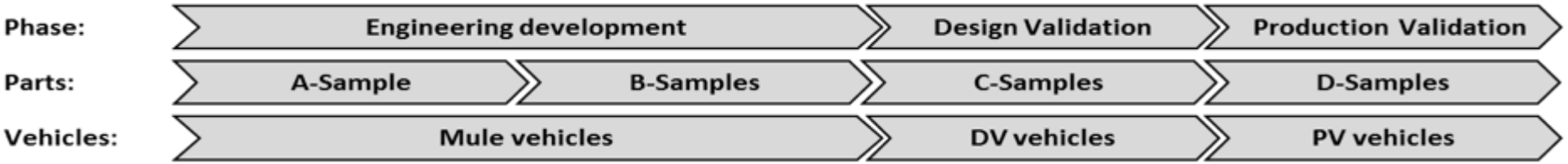
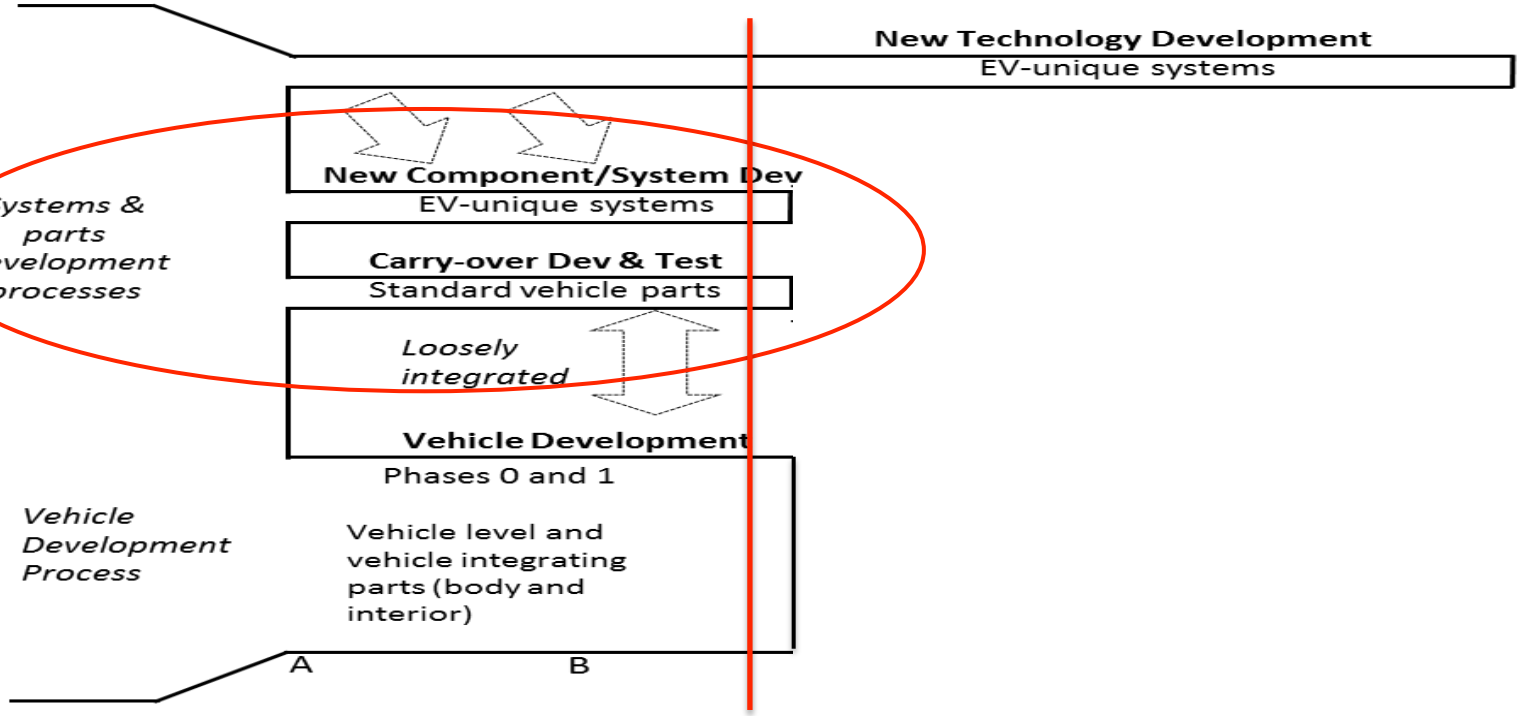
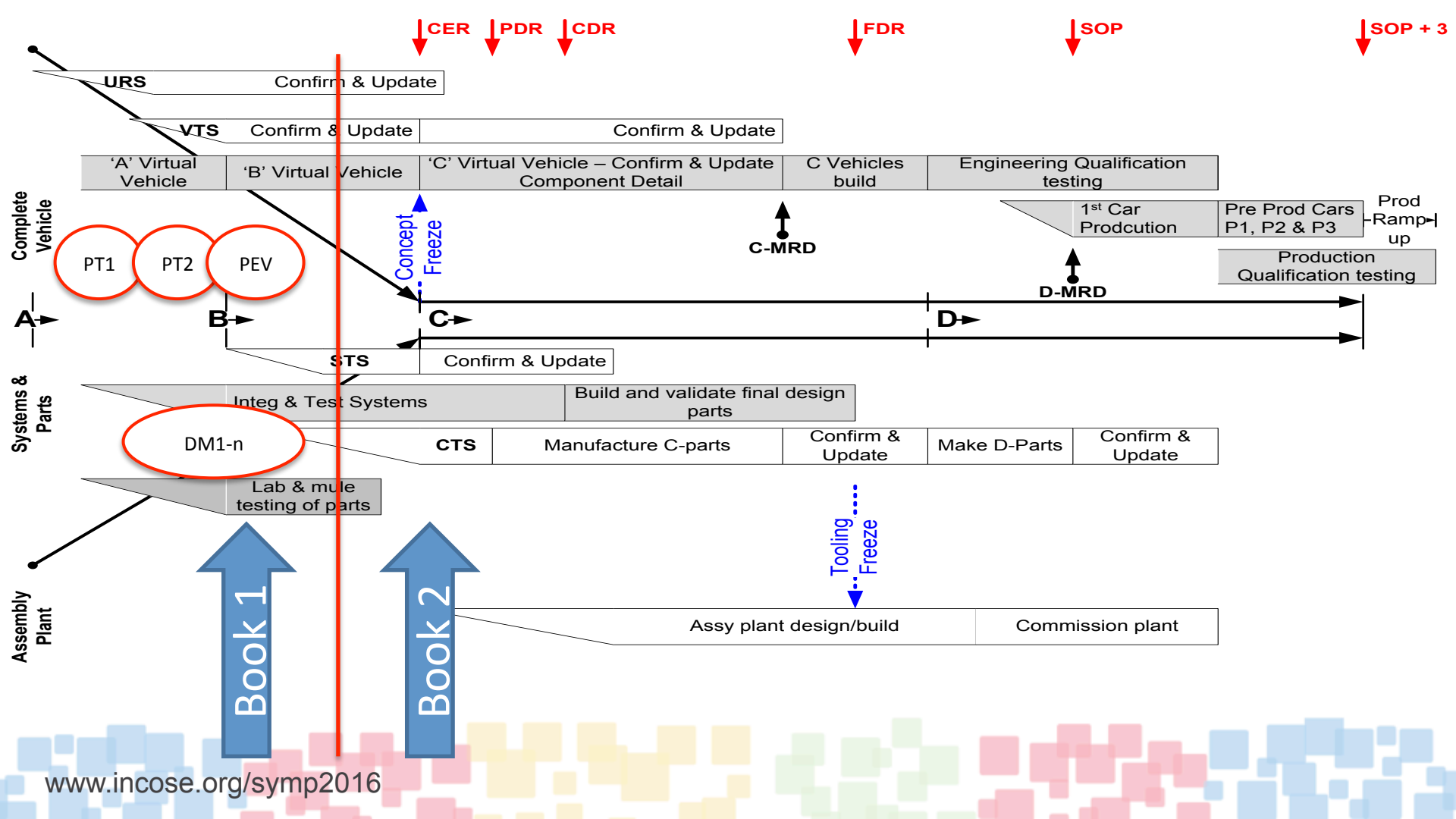


Top-down and bottom-up




CER
PDR
CDR
FDR
SOP
SOP + 3
URS
Confirm & Update
VTS
Confirm & Update
Confirm & Update
'A' Virtual Vehicle
'B' Virtual Vehicle
'C' Virtual Vehicle – Confirm & Update Component Detail
C Vehicles build
Engineering Qualification testing
Complete Vehicle
PT1
PT2
PEV
Concept Freeze
C-MRD
1st Car Prodcution
Pre Prod Cars P1, P2 & P3
Prod Ramp up
Production Qualification testing
D-MRD
A
B
C
D
STS
Confirm & Update
Systems & Parts
Integ & Test Systems
Build and validate final design parts
DM1-n
CTS
Manufacture C-parts
Confirm & Update
Make D-Parts
Confirm & Update
Lab & mule testing of parts
Tooling Freeze
Assembly Plant
Assy plant design/build
Commission plant
Book 1
Book 2

Baseline maturity

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	Book 1	Book 2
Purchasing and Logistics Strategy	●	● ●
Aftersales Strategy	●	● ●
Quality Strategy	●	● ●
Budget (project & vehicle cost)	● ●	● ● ● ●
Plant concepts	●	● ●
Plant technical Specs (PTS)	●	● ●
Concept & detailed design	●	● ●
Vehicle technical Specs (VTS)	● ●	● ● ● ●
Program Master Schedule (PMS)	● ●	● ● ● ●
User Requirements (URS)	● ● ●	● ● ● ●

Conclusion

- Many lessons, only a few discussed
- EV's are different to conventional cars
- A clean-sheet approach has advantages
- It also:
  - Could increase cost from less parts re-use
  - Hampers communication with suppliers
- A hybrid "top-down, bottom-up" model was implemented, but not proven

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Questions?

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