AutoStack Industrie (ASI) Consortium -

Advanced High Performance Stack Technology for Automotive Volume Production

The Results

AERO Hydrogen and Battery Summit

17.04.2024

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Project objective - high performance, low cost stack design and proof of critical mass manufacturing processes

High-performance, low-cost stack technology

- Ultimate power density
- Matching target cost
- Commercially ready

Utilization of industrial scale effects

- Joint stack specification
- Scalable power
- Modular stack platform

Mass manufacturing capability

- Manufacturing technology
- Meeting quality and cost
- Factory planning

Automotive manufacturers, suppliers and researchers in one team

AutoStack Industrie (ASI)

Joint initiative of the German automotive and supply industry

OEM	Suppliers	Research
Audi, BMW, Daimler, Ford, Volkswagen	Dana, Freudenberg, Greenerity, cellcentric, PowerCell, umicore	ZSW

- Total value chain approach
- 12 partners
- Comprehensive expertise and resources
- Budget 60 Mio. € - co-funded by NOW
- Duration 2017 - 2022

Collaboration model along value chain to fully utilize expertise

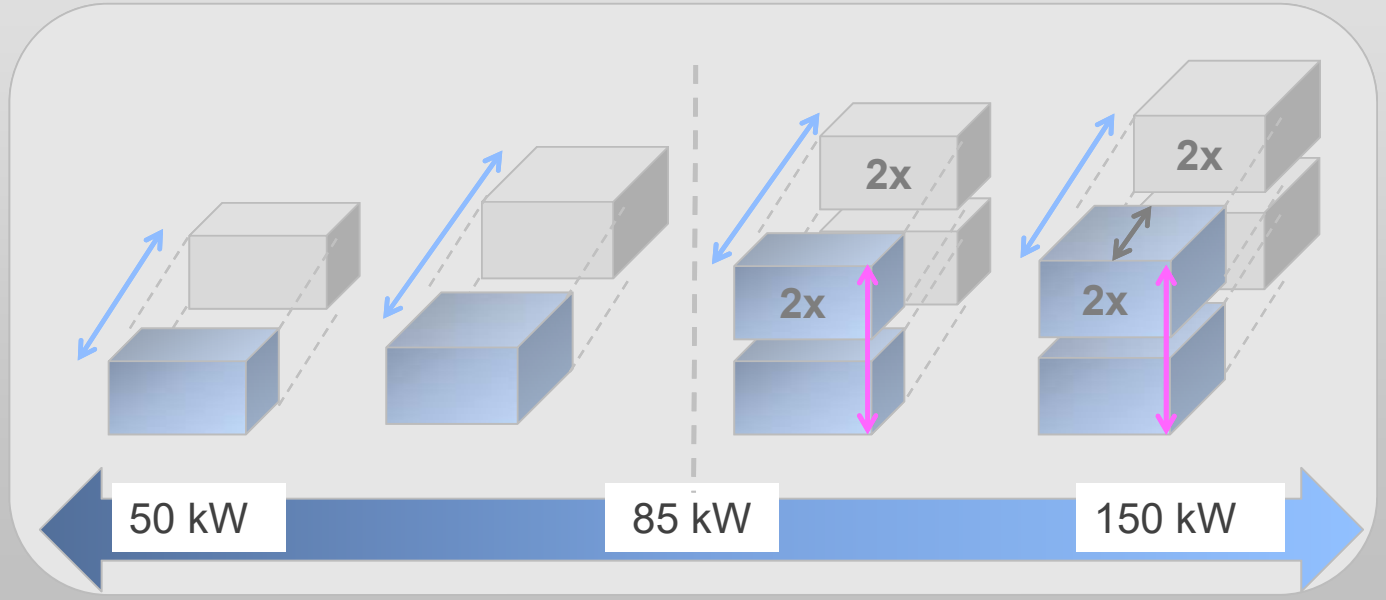
- ✓ Cross-functional team work/
- ✓ Focus on critical path/
- ✓ Monitoring of interfaces/
- ✓ Joint gap analysis and mitigation/

AP0
ZSW
Projektplanung, Koordinierung, Administration, QS-Koordinierung (BMW)

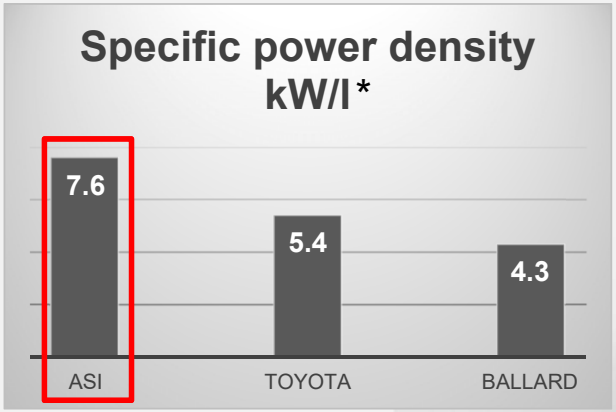
AP1 VW	AP2 Umicore	AP3 Greenerity	AP4 DANA	AP5 PCS/PCG	AP6 ZSW	AP7 PCS/PCG	AP8 ZSW	AP9 ZSW
Stack-Spezifikation & Assessments	Katalysator- und GDL-Entwicklung	MEA-Entwicklung	BPP-Entwicklung	Stack-Design	Stack-Test & Validierung	Stack-Fertigungs-entwicklung & Erprobung	Nutzungskonzept, Dissemination	Wissenschaftliche Begleitforschung
1.1 System-Anforderungen & Packaging	2.1 Kat.-Fertigungs-Entwicklung & Kostensenkung	3.1 Membran, Katalysator & GDL Auswahl	4.1 Spezifikation metallische BPP	5.1 Konzeptentwicklung & Komponenten - Spezifikation	6.1 Testprogramm, Planung & Koordinierung	7.1 Potenzialanalyse, Prozessdesign & Simulation	8.1 Industrielles Nutzungskonzept Automotive	9.1 MEA-Mikro/Nano-Struktur
1.2 Betriebsbedingungen & Betriebsstrategie	2.2 Katalysatorfertigung & Lieferung	3.2 MEA-Entwicklung mit ausgewählten Materialien	4.2 Material- & Beschichtungs-Konzepte	5.2 Stack-Konstruktion	6.2 Leistungstests	7.2 Aufbau, Validierung & Optimierung einzelner Teilprozesse	8.2 Industrielles Nutzungskonzept andere Apps	9.2 Strömungsverhalten Zelle/Stack
1.3 Stack-Spezifikation	2.3 GDL- Fertigungs-entwicklung	3.3 MEA-Tests & Qualifikation	4.3 Verteilerplatten-Konstruktion & Schnittstellen	5.3 Komponenten-Beschaffung & Stack-Fertigung	6.3 Dauertests	7.3 Konzept Fertigung 30000 Einheiten	8.3 Dissemination	9.3 Stack-Betriebsverhalten
1.4 Stack-Kostenanalyse & Verfolgung	2.4 GDL- Anpassung & Auswahl	3.4 MEA-Muster-Fertigung & Lieferung	4.4 BPP-Korrosionstest		6.4 Umwelttests	7.4 Konzept In-Line-Prüfung		9.4 Stack-Herstelltechnik
	2.5 GDL- Fertigung		4.5 BPP-Muster-Fertigung & Lieferung		6.5 Konstruktions-Prüfung & Änderungsdienst	7.6 Potentialbewertung		9.5 Anforderungen und Potential sonstige Apps
			4.6 BPP-Fertigungs-Entwicklung					9.6 Entwicklungsstand/ Benchmarks

Scalability to enable various power and packaging requirements

Variation of stack power by cell count and combination of modules



ASI stack product features outstanding properties

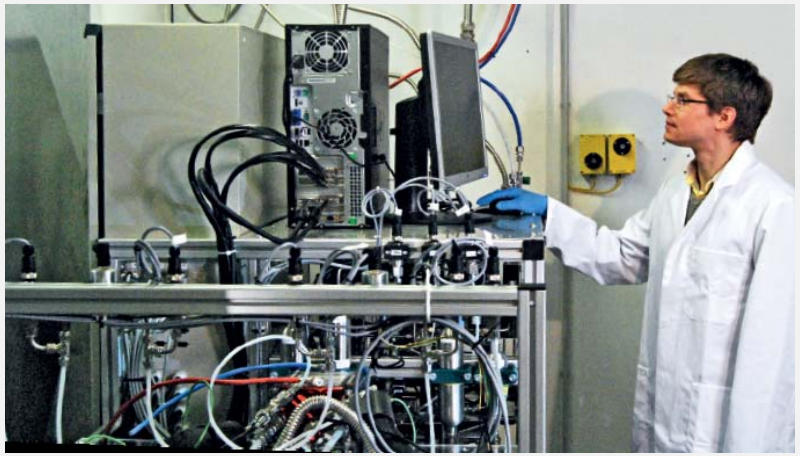


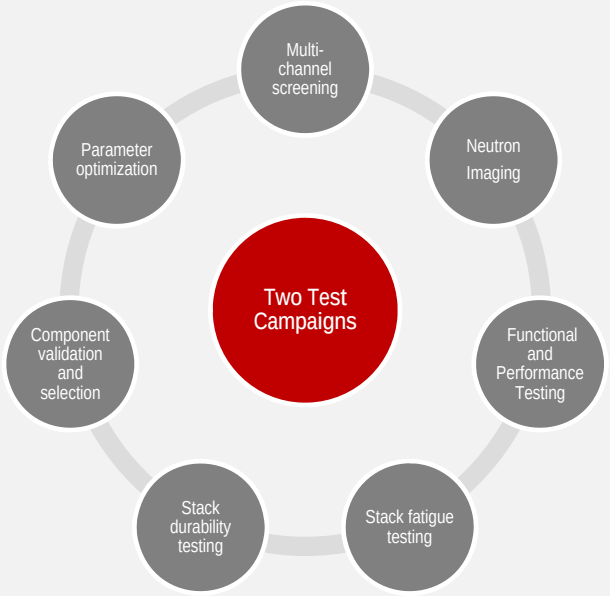
Full stack volume	dm^3	20.35
Stack volume w/o end plates	dm^3	12,82
Full stack weight	kg	25.7
Current density (nom/max)	A/cm^2	2.0/2.5
Power (nom/max)	kW	86,4/97,4
Volumetric power density (nom/max)	kW/dm^3	4,2/4,7
Specific power density (nom/max)	kW/dm^3	6.7/7.6
Cell count		275

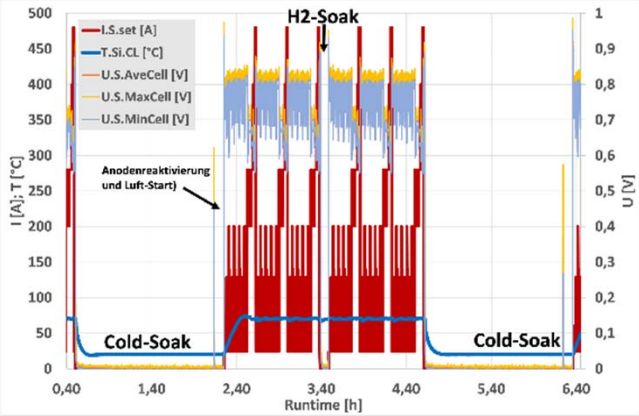
* Sources:
https://www.bing.com/search?q=New+Mirai+Hydrogen+Fuel+Cell+Electric+Vehicle+–+Under+The+Skin+–+FuelCellsWorks&go=Suche&qs=n&form=QBRE&sp=-1&pq=new+mirai+hydrogen+fuel+cell+electric+vehicle+–+under+the+skin+–+fuelcellsworks&sc=1-79&sk=&cvid=09026BC6DDB04D84973981FB53E12546&ghsh=0&ghacc=0&ghpl=)
https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/14/ballard-launches-industry-leading-high-power-density-fuel-cell-stack-for-vehicle-propulsion

Functionality and robustness validated in full automotive test program

86 stacks with more than 30 000h operation in automotive load cycles.





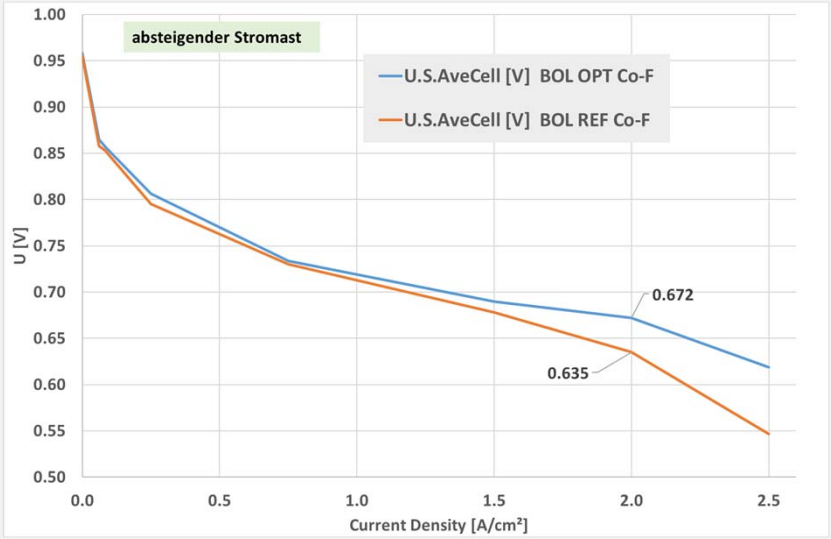


Accelerated testing

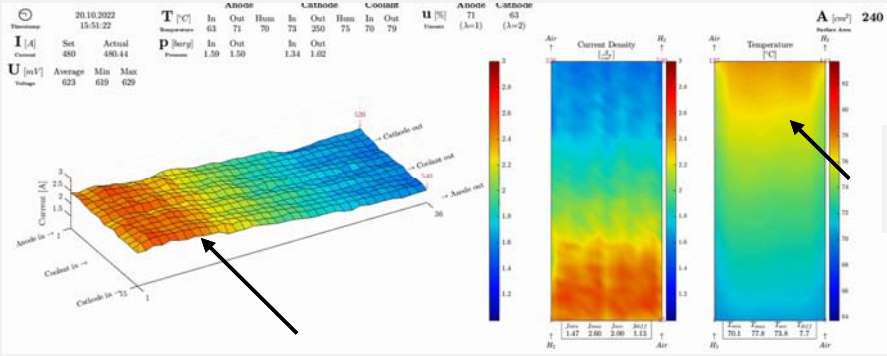
- Thermal stress by regular soak times
- More than 2400 enforced air-air-starts
- Instant dynamic operation in cold condition
- Regular hot operation

Optimization of Operating Conditions
(Stack #21)

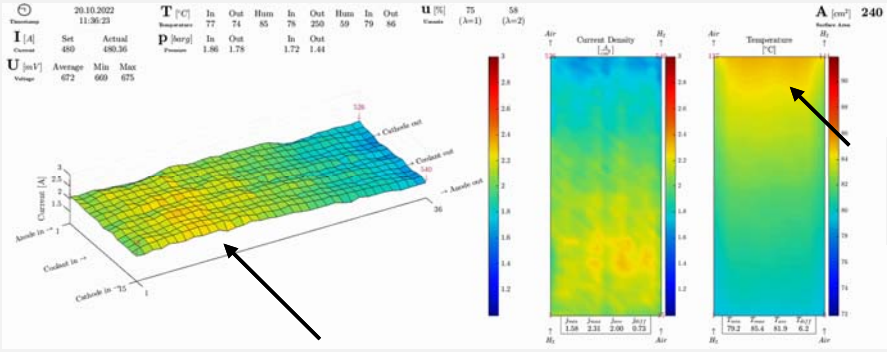
Example: Operation in Co-Flow



→ Optimization of operating conditions improves performance and shows potential to be beneficial for endurance!

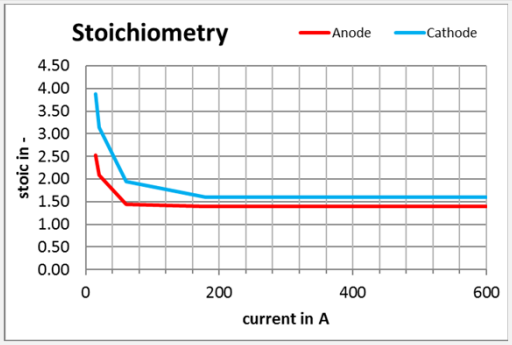


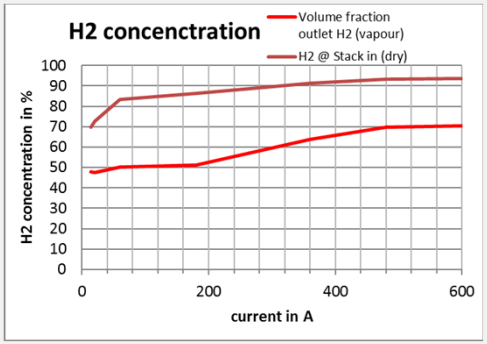
Reference conditions
Co-Flow @480A!

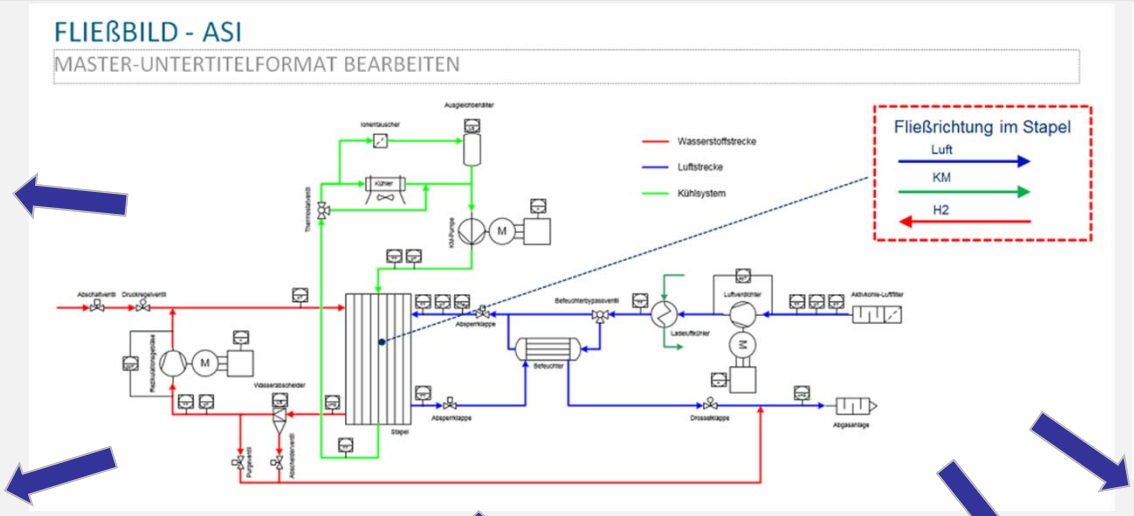


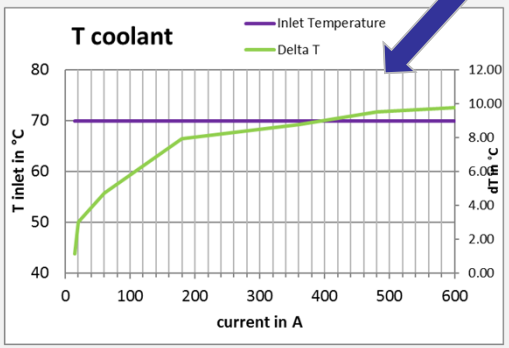
Optimized conditions
Co-Flow @480A!

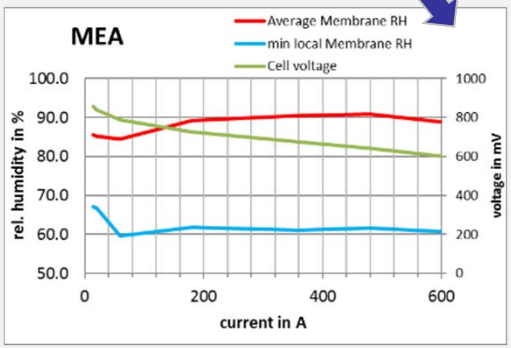
Stack Operating Conditions Were Based on a System Model

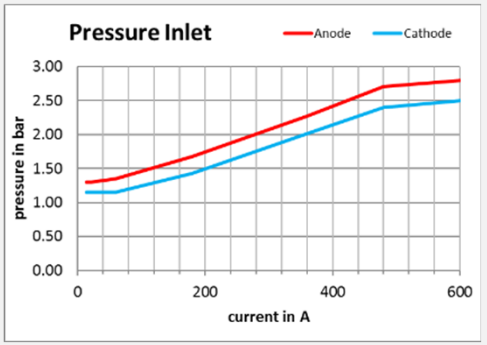












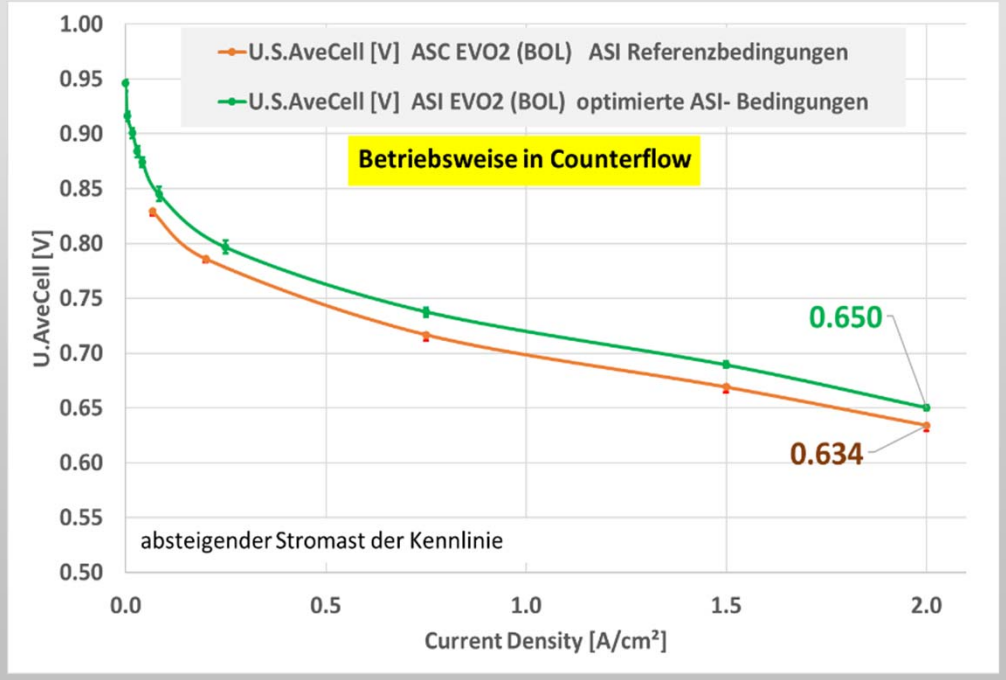
Operating conditions obtained from system modelling by VW. Later refined exprimentally.

Additional requirements

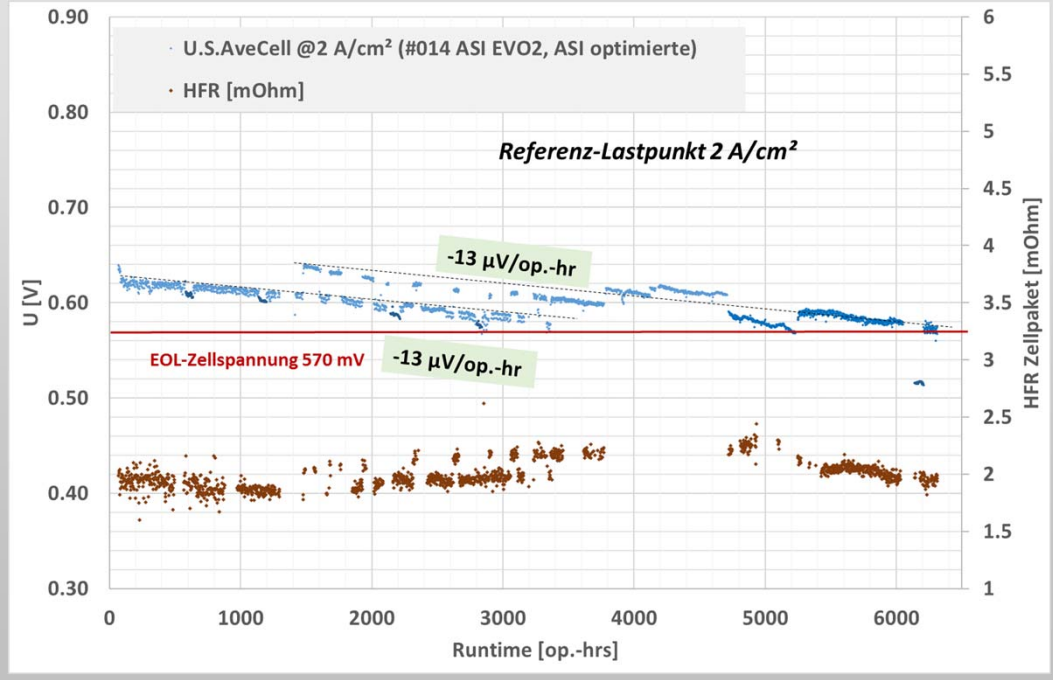
- **CO-Tolerance**
- **Cell reversal tolerance**

Various contributions were delivered to a challenging design…

Cell voltage raised by 16mV/cm² vs. prior generation

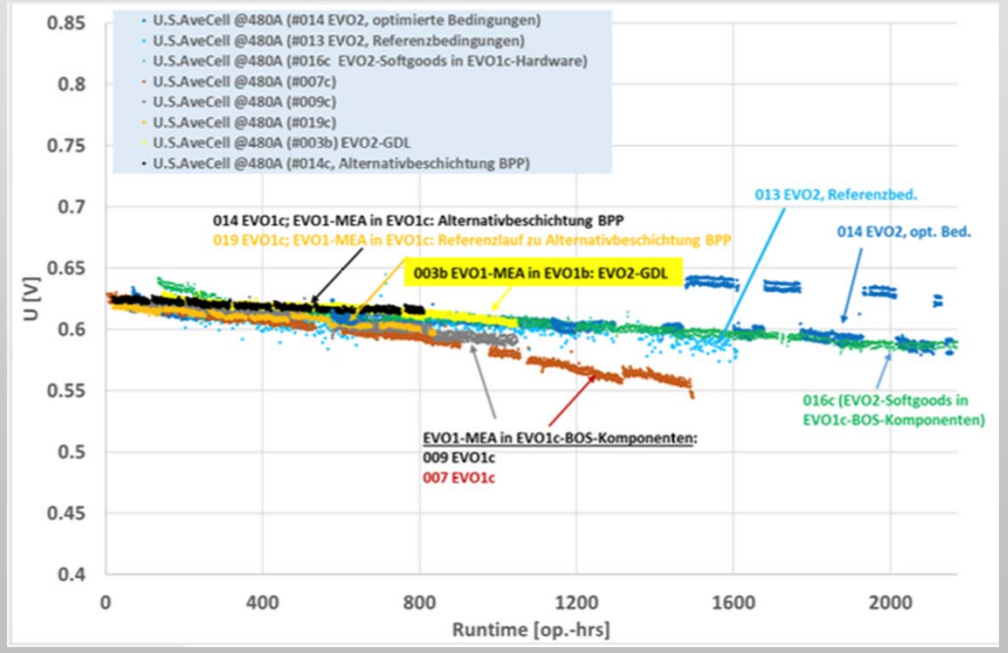


Durability proven in accelerated cycle

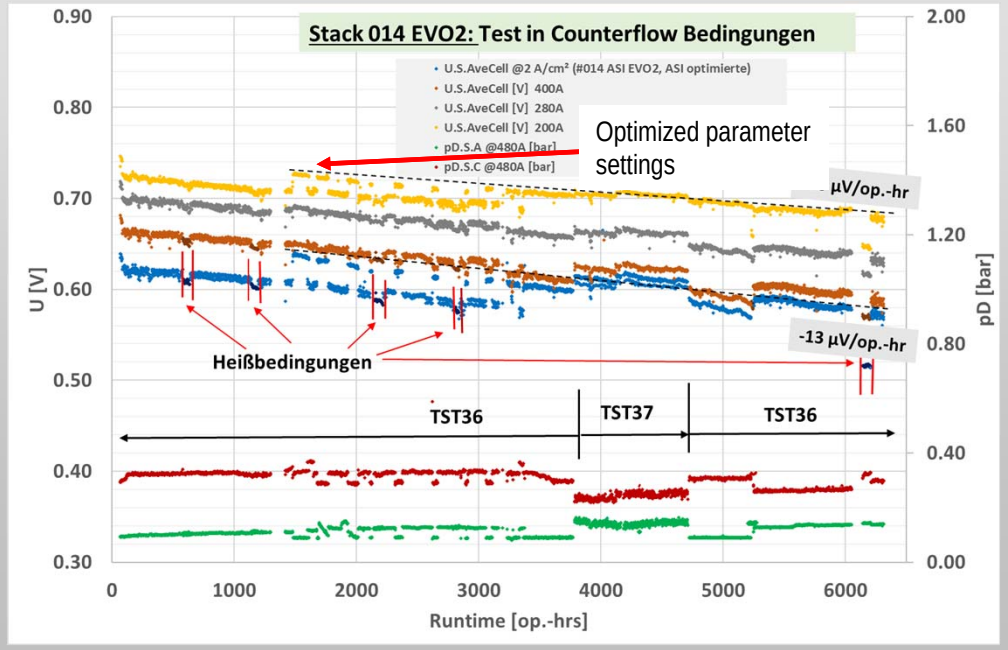


Strong gains by design, optimised component fit and parameter settings

Reduction of stack degradation over development



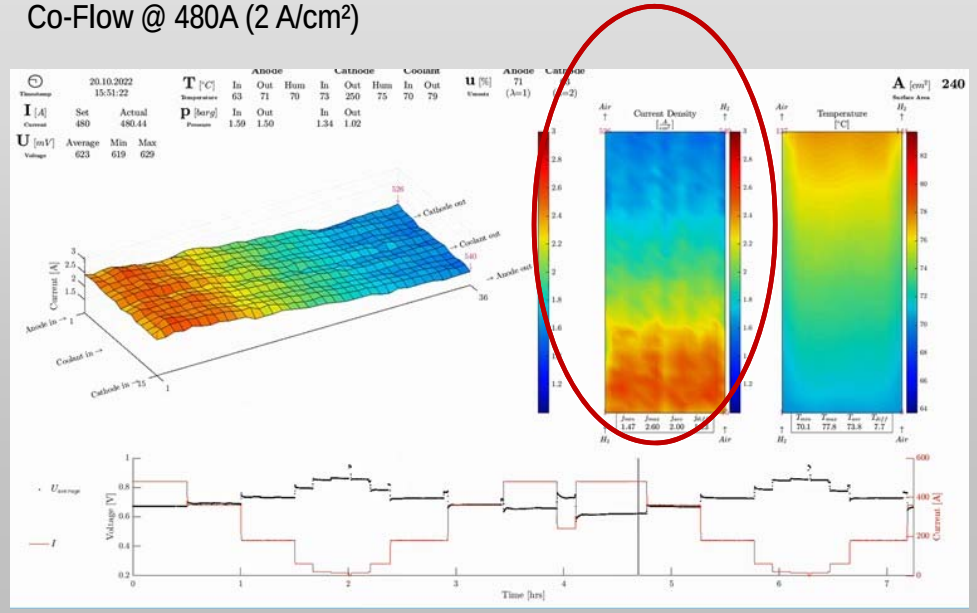
Increase of cell voltage by tuning operation parameters



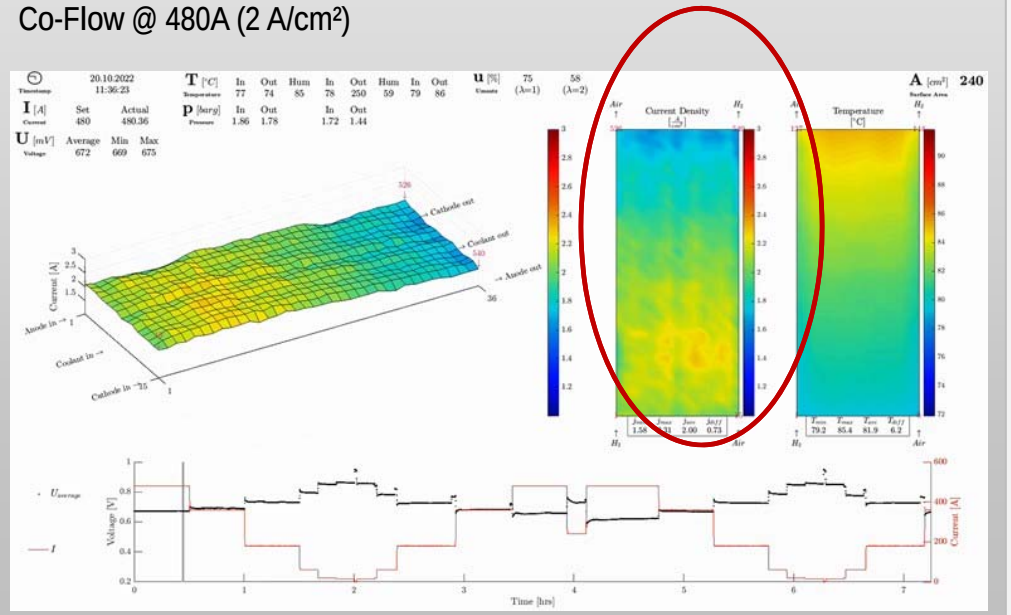
Current distribution tuned to supporting durability

Parameter settings provide critical impact on current distribution

Reference conditions
Co-Flow @ 480A (2 A/cm²)

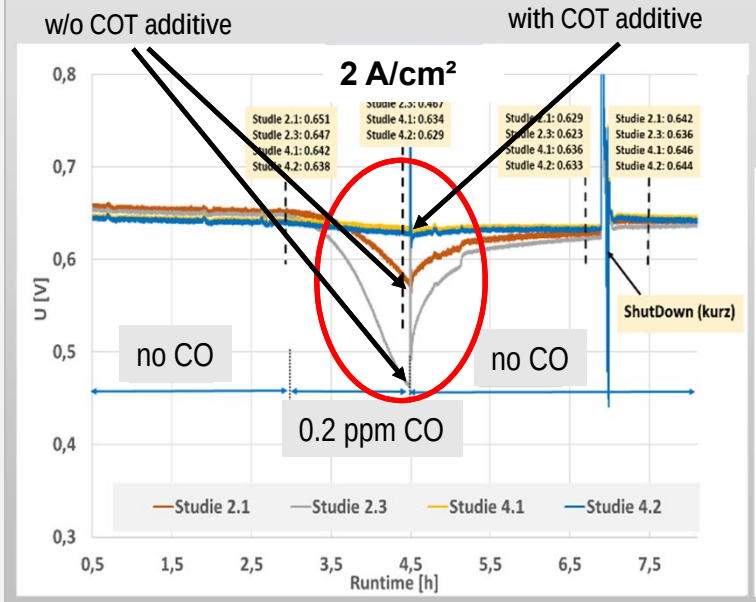


Optimised operation parameter
Co-Flow @ 480A (2 A/cm²)



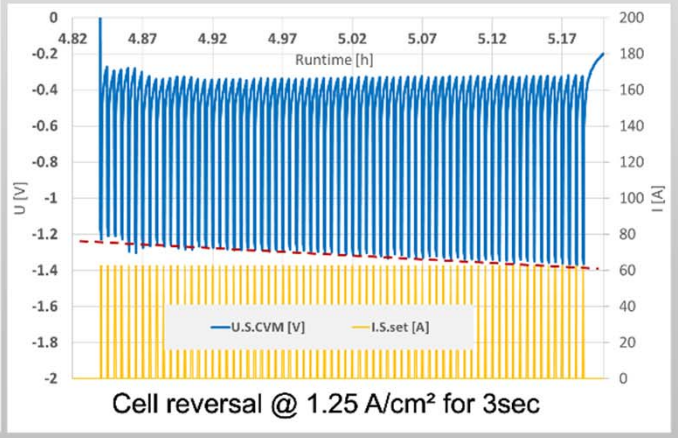
CO and cell reversal tolerance for more robustness under severe conditions

CO tolerance (COT)

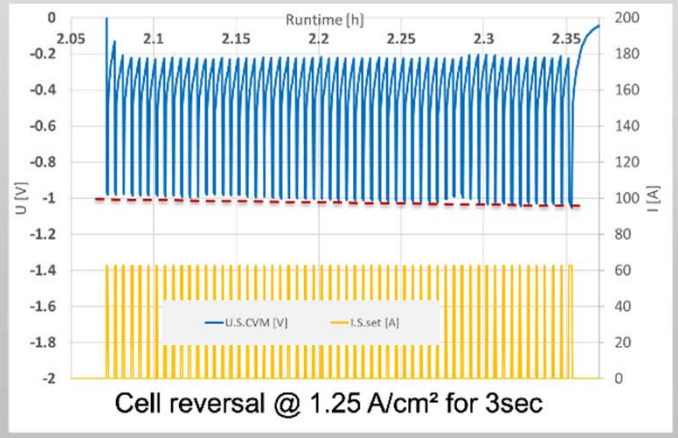


Cell reversal tolerance (CRT)

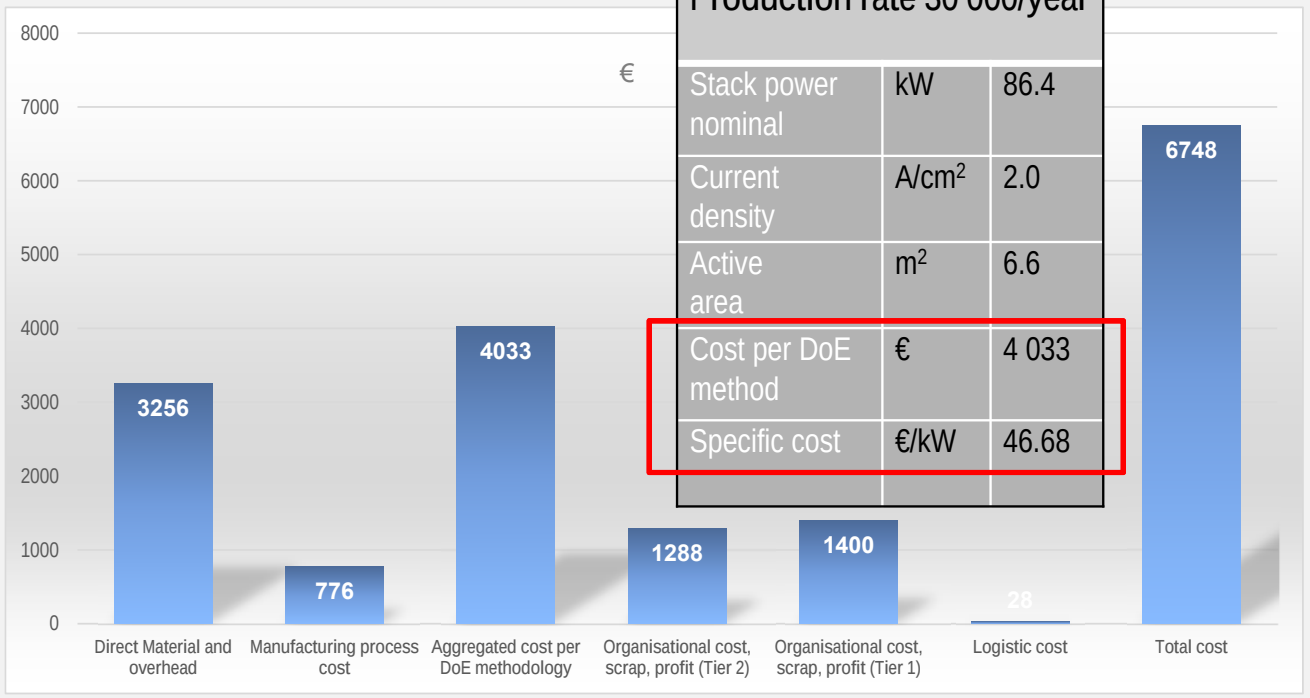
w/o CRT additive, irreversible degradation



with CRT additive, stable cell performance over time



In-deep cost-to-manufacturing analysis reflecting actual cost levels

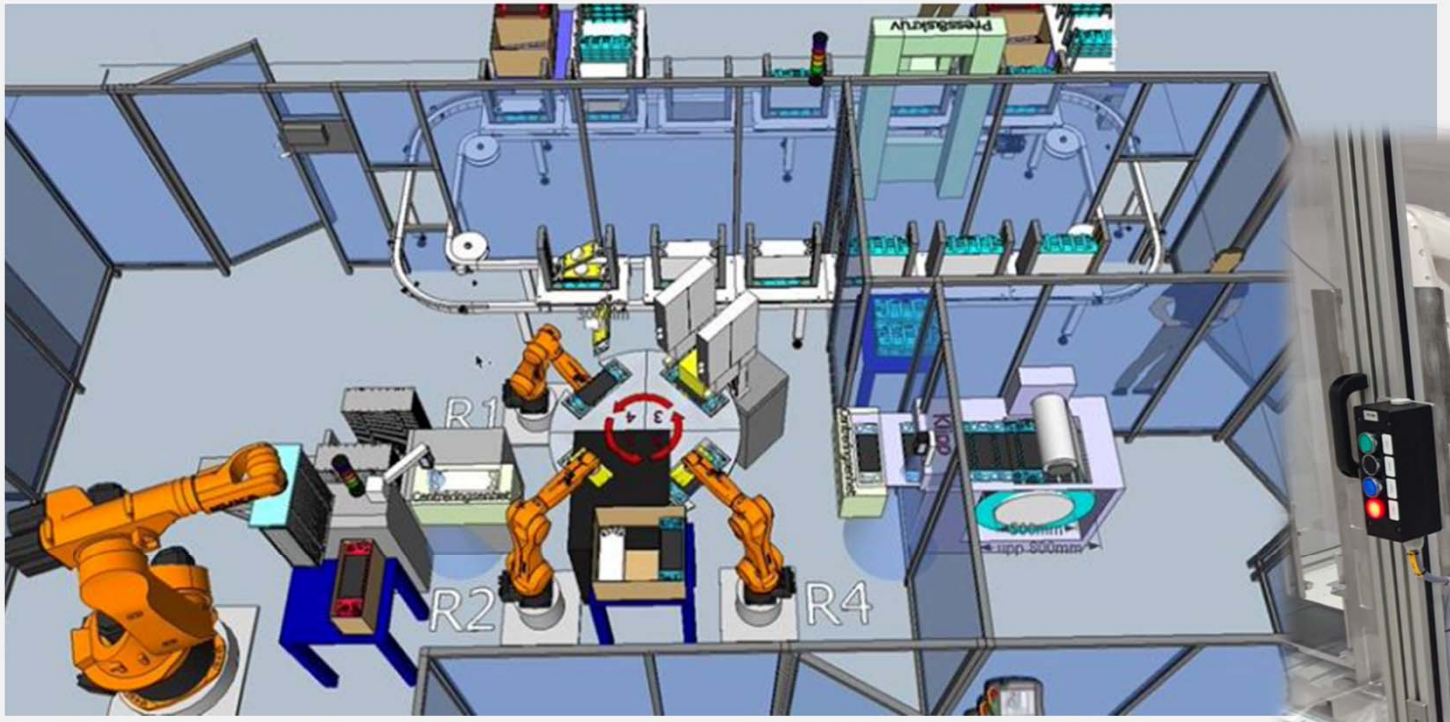


Production rate 30 000/year		
Stack power nominal	kW	86.4
Current density	A/cm²	2.0
Active area	m²	6.6
Cost per DoE method	€	4 033
Specific cost	€/kW	46.68

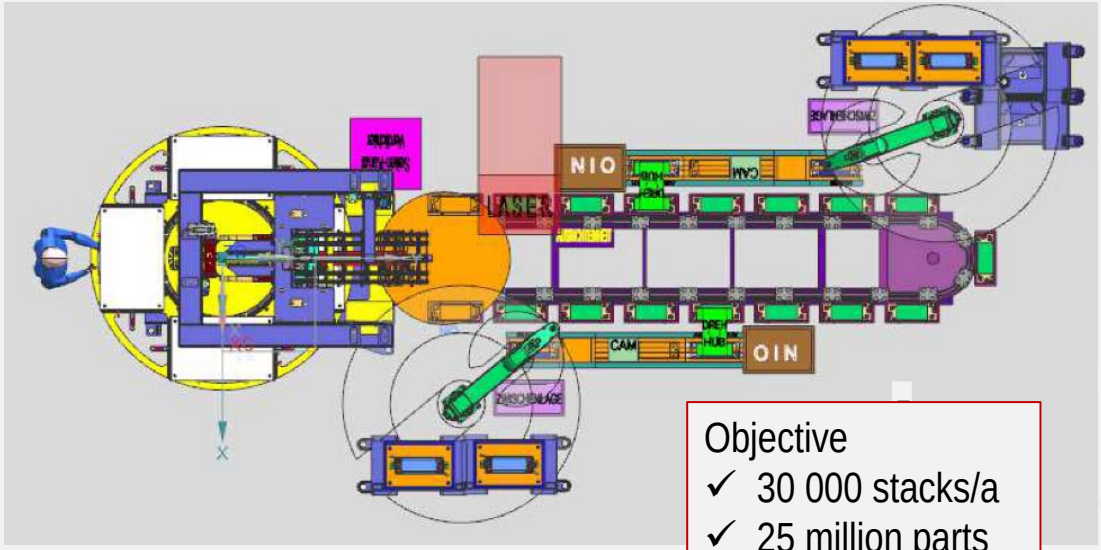
- Pt-loading 0,4mg/cm² (due to technical trade-off)
- Including CRT/COT-tolerance for better robustness under severe conditions
- Actual manufacturing and material cost including increased raw material prices
- Further potential for improvement

Pt-content 0.4mg/cm² ; including CRT/COT; Pt-price 883$/tr.oz.; 1$=0.91€ (July-Sep 2019)

Robotic assembly proven for manufacturing of 10 000 stacks/a

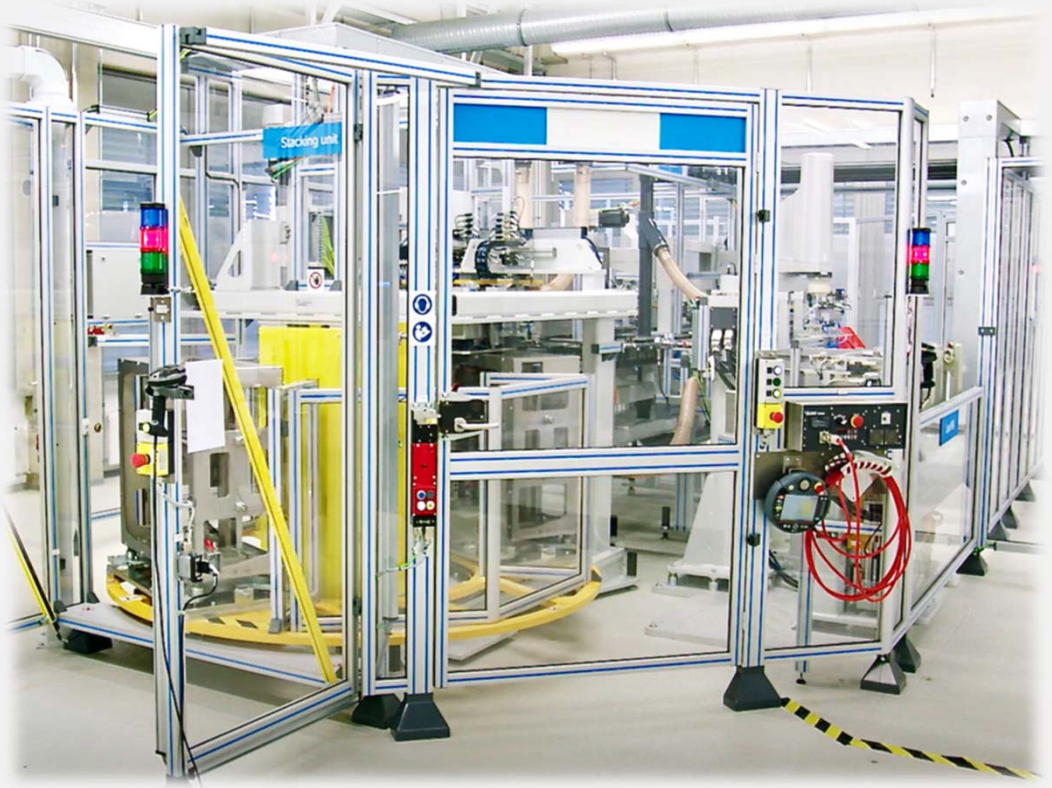


Automated assembly for 30 000/a stacks meets principal requirements



Objective

- ✓ 30 000 stacks/a
- ✓ 25 million parts
- ✓ 2 parts per sec
- ✓ APQP
- ✓ Max. 3,2 failures per million parts

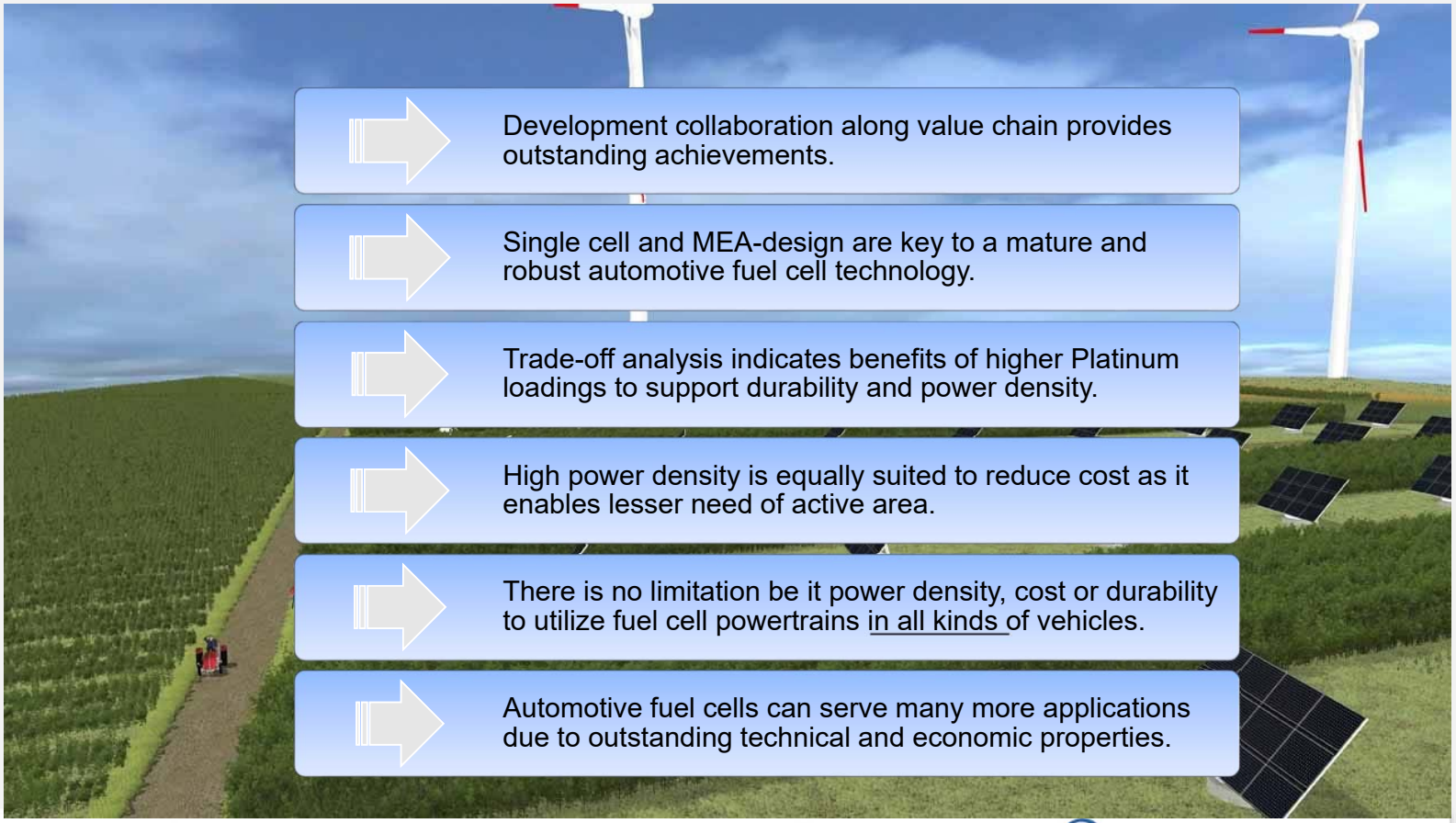


Energy security requires immediate and balanced action

- Recent events shed a new light on securing energy supply.
- All technology options shall be considered to mitigate threats in energy supply and establish a sustainable approach.
- Hydrogen can play a central role also in the transport sector but implementation needs more pace.

Final considerations in support of vehicle electrification strategy

Fuel cells and hydrogen can deliver a critical tool to reconstruct a volatile energy world. The technology is there.



Thank you for your attention!

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