System Level Test for Automotive Devices - A Thermal Perspective

See Jean “Sid” Chan
Wee Tick Lo
AEM Singapore

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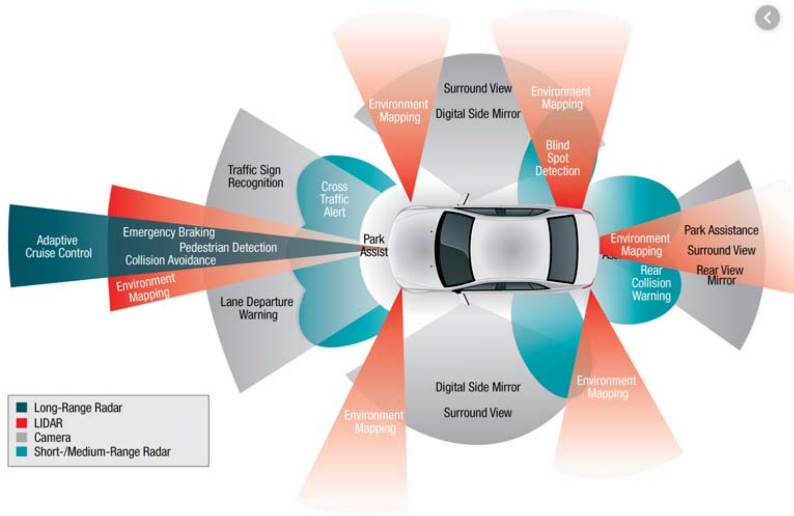
- Challenges of Automotive Device Testing
- AEM's Approach To Address The Challenges
- Summary & Closing

Challenges With Automotive Testing

- Increase in the number of components and complexity.
- Mission critical applications with zero tolerance for error.
- From Defects per Million to Defects per Billion



Source : Researchgate

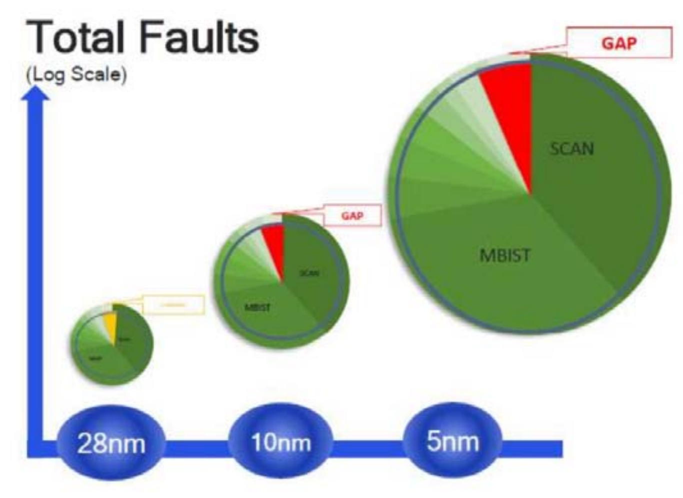
Advanced Driver Assistance Systems

Automotive industry demands extended reliability on parts.

Challenges With Automotive Testing

Advanced semiconductor process nodes

- The Auto industry is now driving the need for new process nodes. ADAS parts are now moving to 7nm and below.
- In the past automotive parts took advantage of mature process nodes.
- The automotive industry now demands same time to market and Semiconductor process as other leading edge technologies



Source: Qualcomm Mike Campbell

Process Node ↓ ***Number of Transistors*** ↑ ***Gap in Test Coverage*** ↑

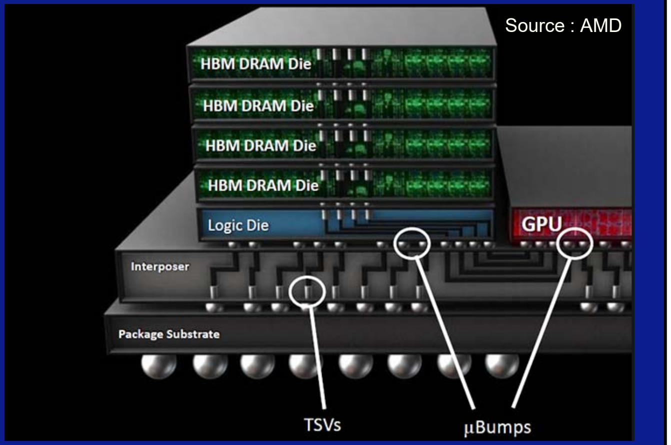
Challenges With Automotive Testing

Component design

- EDA and DFT tools are not adequate to detect today's failures, and designs have reduced margins.
- More transistors increase challenge to detect thermal related failures

Manufacturing assembly

- New package technologies are more sophisticated with new fault modes.
- Parts are subject to more rigorous environments with extended temperature ranges.



Source : AMD

2D, 2.5D, 3D package technologies

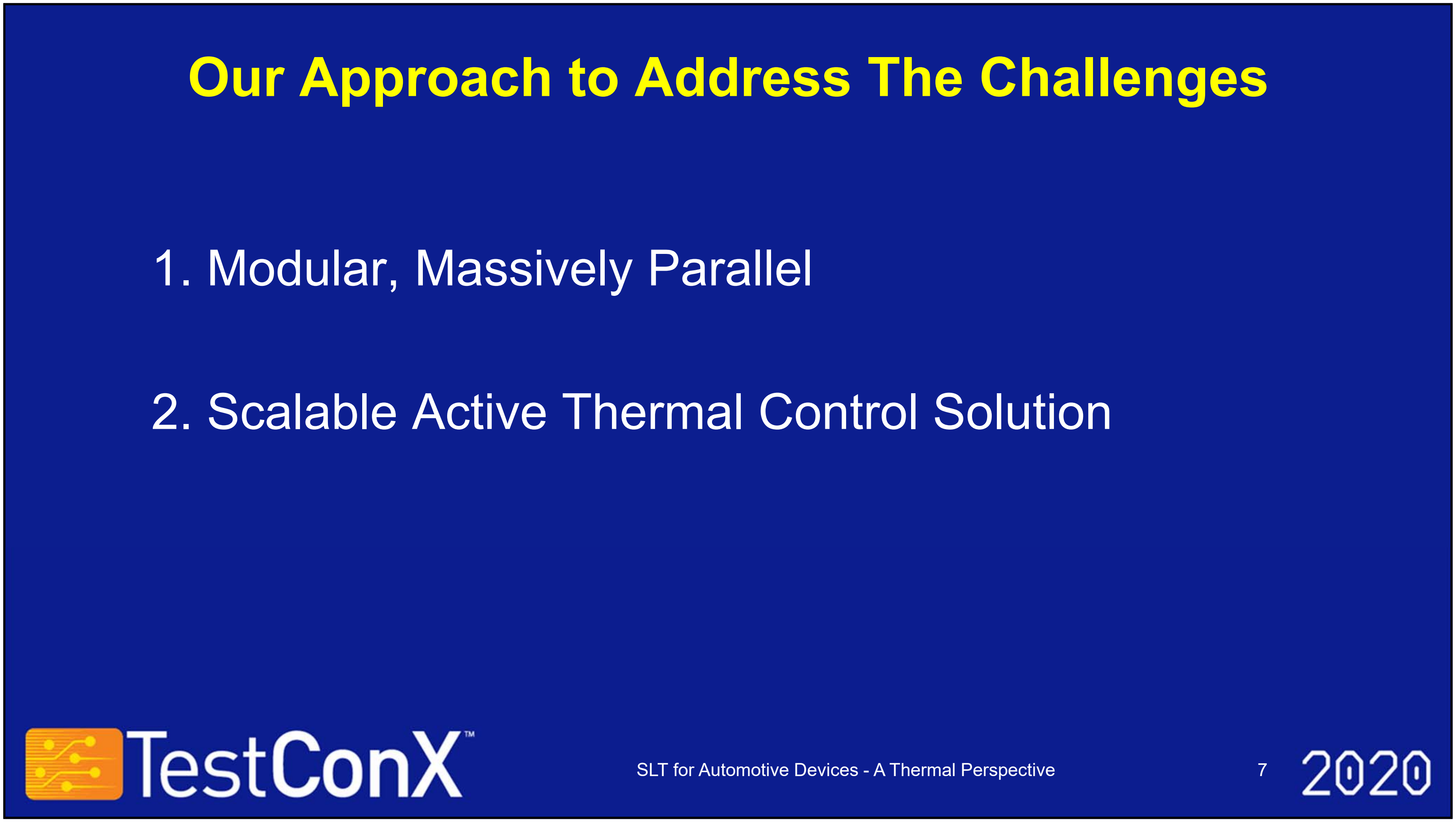
Semiconductor parts are getting more complex and more thermal sensitive.

System Level Test Paradigm

A new test methodology

- **System level test** is becoming a mainstream test to simulate the final application environment.
- System level test times tend to be longer than traditional test flows (minutes vs. seconds) to enable the ability to catch additional defects and validate process corners.
- To enable system test as a cost effective solution requires **high levels of parallelism.**
- Thermal stress testing and **thermal management** during test is an important parameter for testing device corners and device margins.
- Thermal solutions now need to support per site thermal management on highly parallel systems

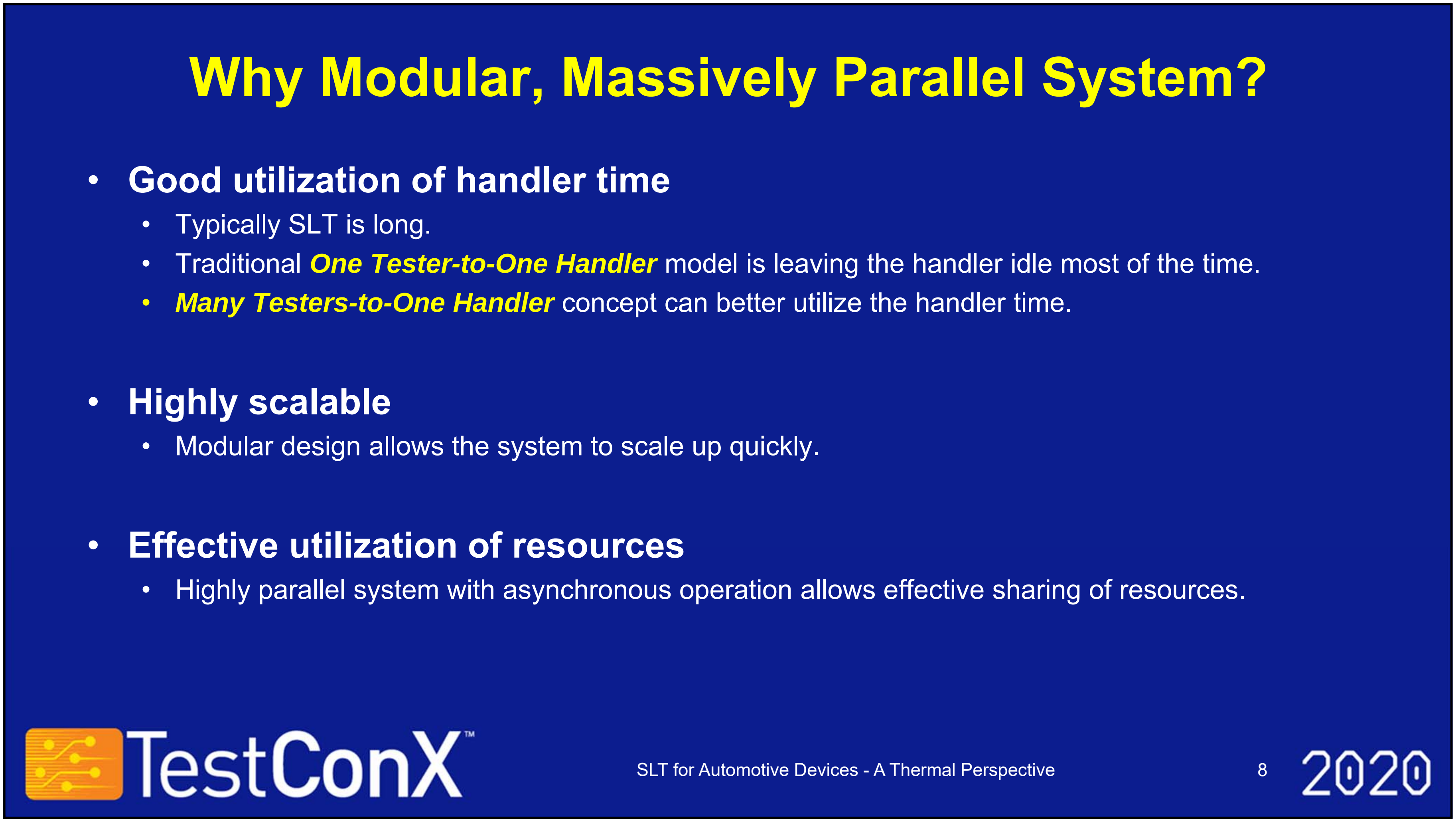
System Level Test with high parallelism and thermal management.



Our Approach to Address The Challenges

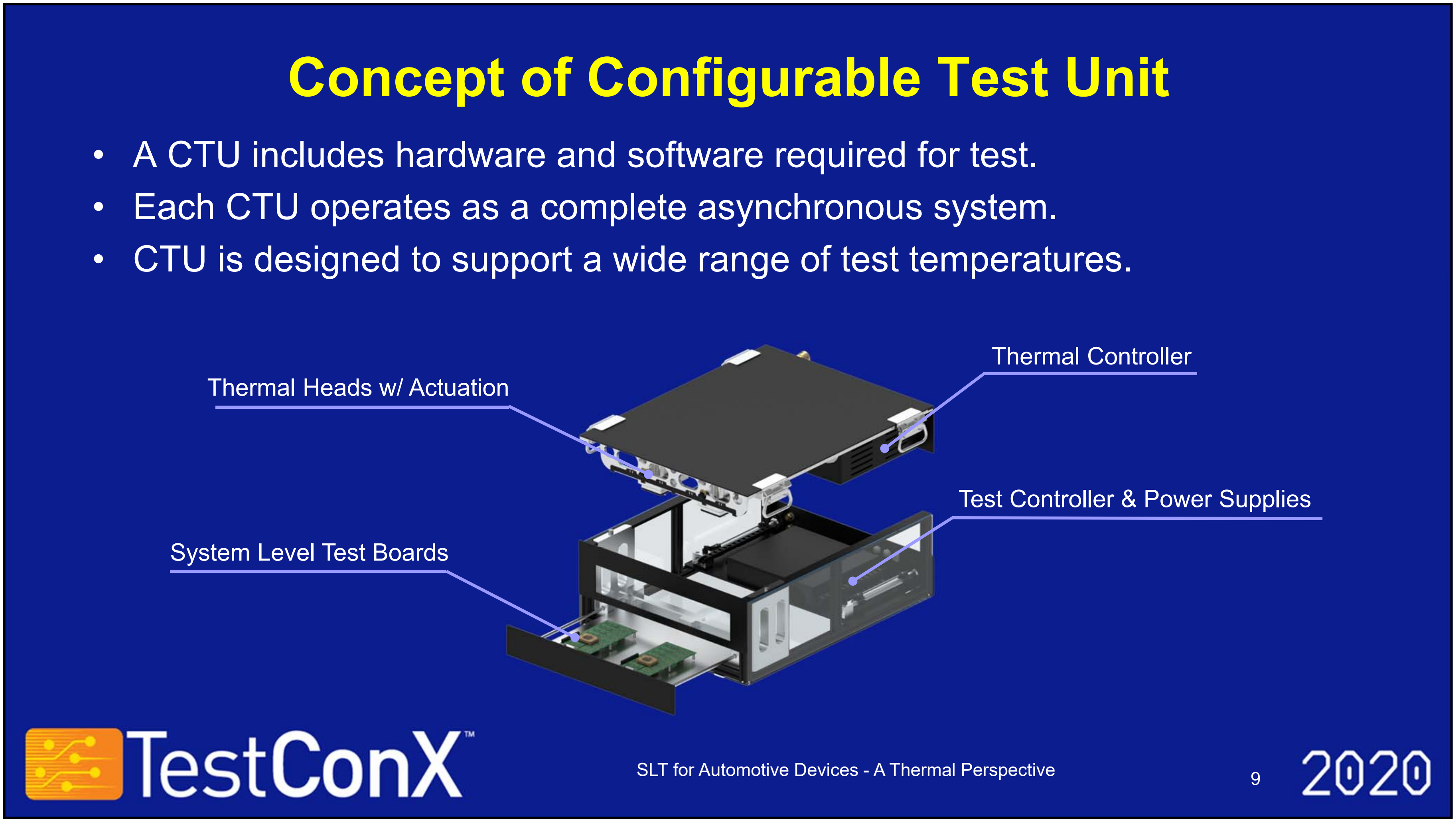
1. Modular, Massively Parallel

2. Scalable Active Thermal Control Solution



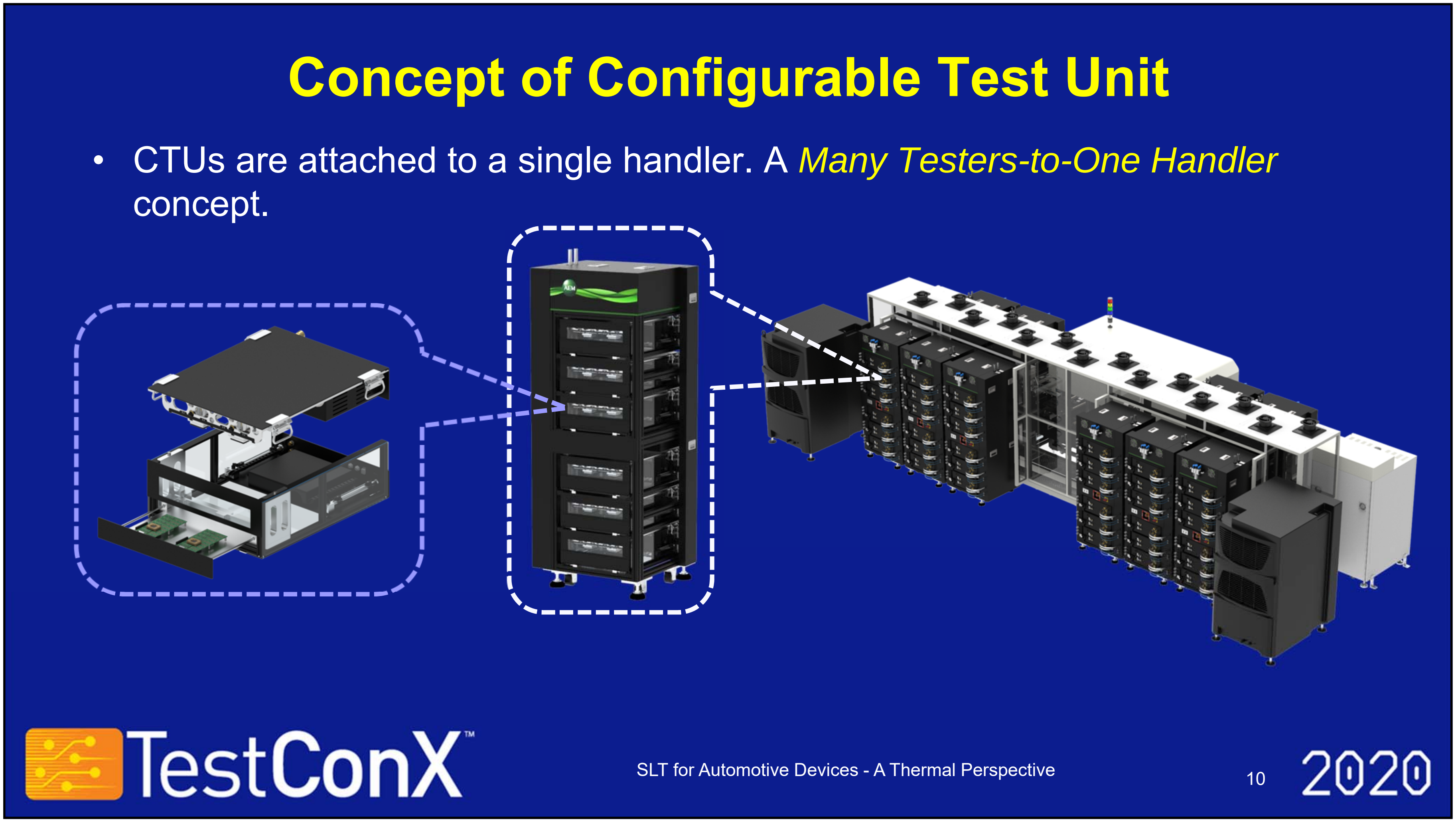
Why Modular, Massively Parallel System?

- **Good utilization of handler time**
  - Typically SLT is long.
  - Traditional ***One Tester-to-One Handler*** model is leaving the handler idle most of the time.
  - ***Many Testers-to-One Handler*** concept can better utilize the handler time.
- **Highly scalable**
  - Modular design allows the system to scale up quickly.
- **Effective utilization of resources**
  - Highly parallel system with asynchronous operation allows effective sharing of resources.



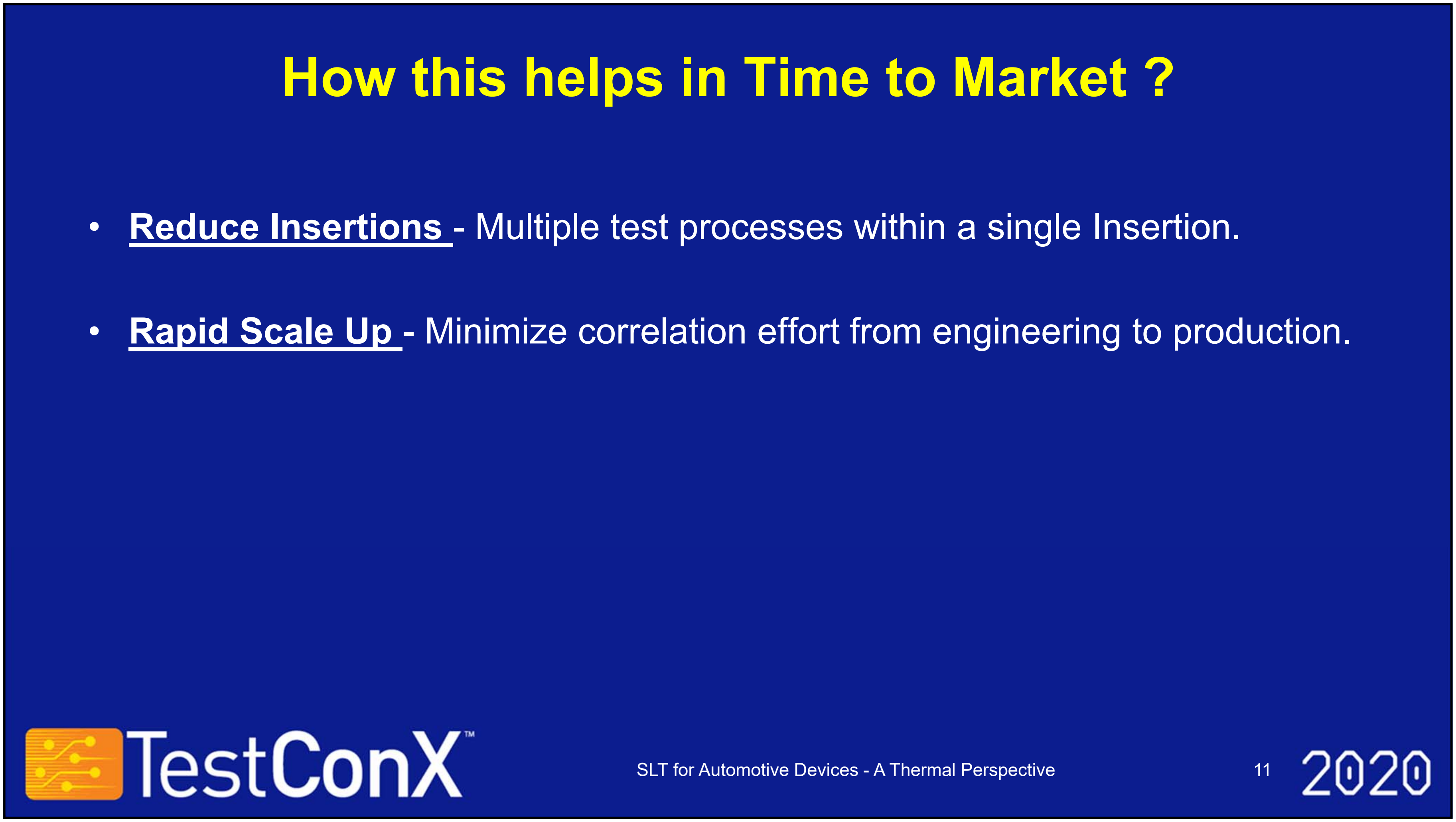
Concept of Configurable Test Unit

- A CTU includes hardware and software required for test.
- Each CTU operates as a complete asynchronous system.
- CTU is designed to support a wide range of test temperatures.



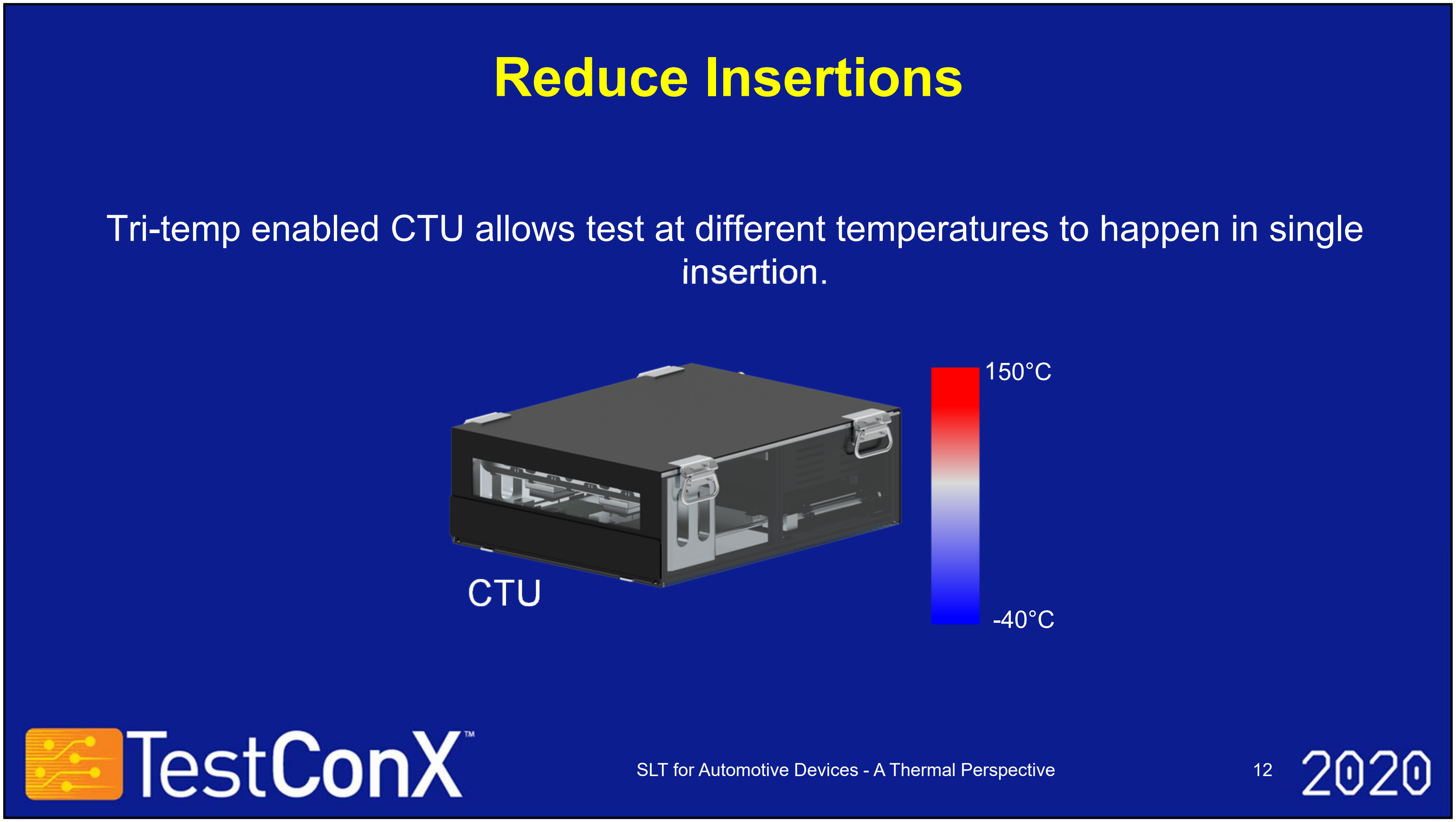
Concept of Configurable Test Unit

- CTUs are attached to a single handler. A *Many Testers-to-One Handler* concept.



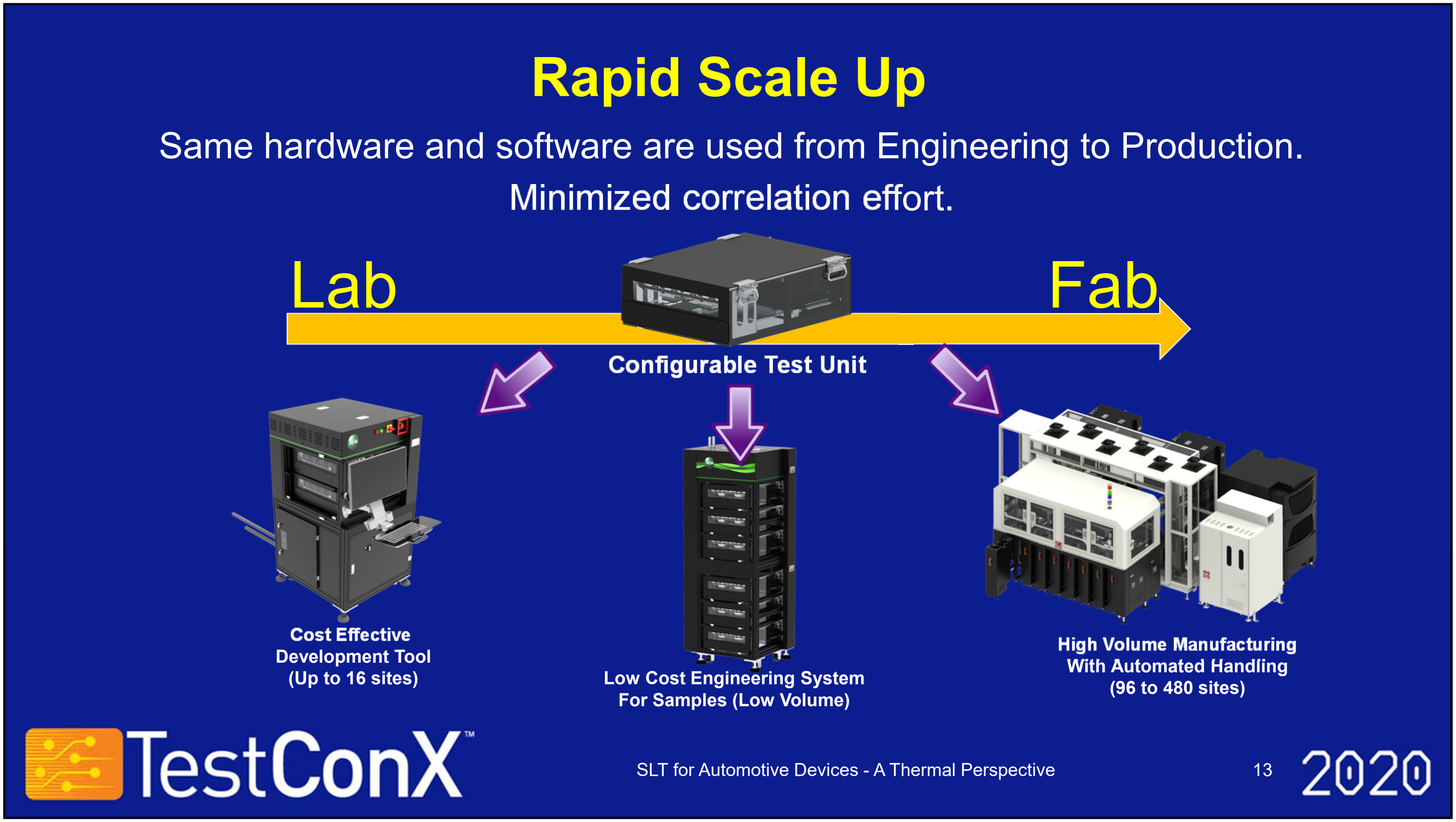
How this helps in Time to Market ?

- **Reduce Insertions** - Multiple test processes within a single Insertion.
- **Rapid Scale Up** - Minimize correlation effort from engineering to production.



Reduce Insertions

Tri-temp enabled CTU allows test at different temperatures to happen in single insertion.



Rapid Scale Up

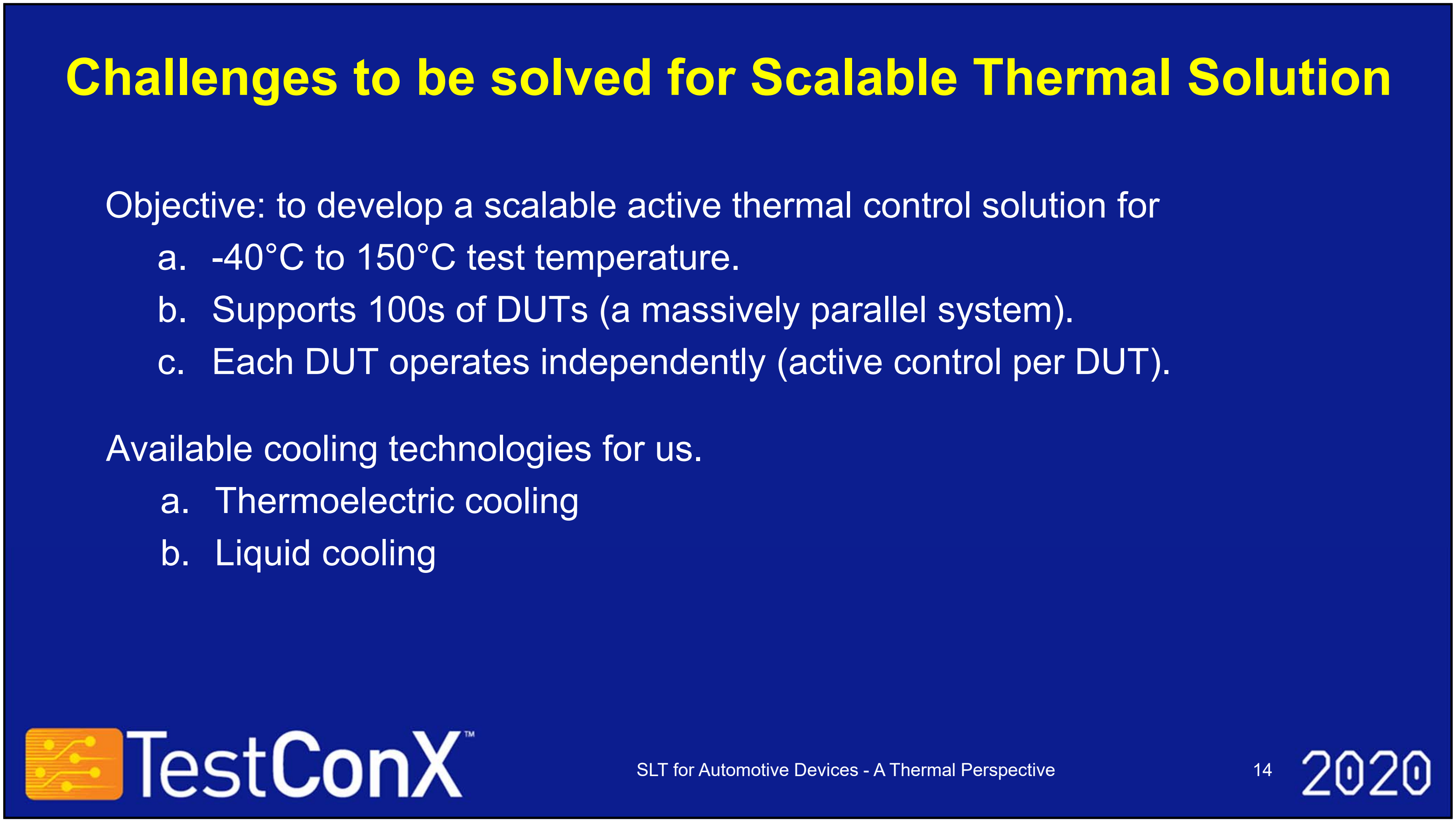
Same hardware and software are used from Engineering to Production.
Minimized correlation effort.

Configurable Test Unit

Cost Effective Development Tool (Up to 16 sites)

Low Cost Engineering System For Samples (Low Volume)

High Volume Manufacturing With Automated Handling (96 to 480 sites)



Challenges to be solved for Scalable Thermal Solution

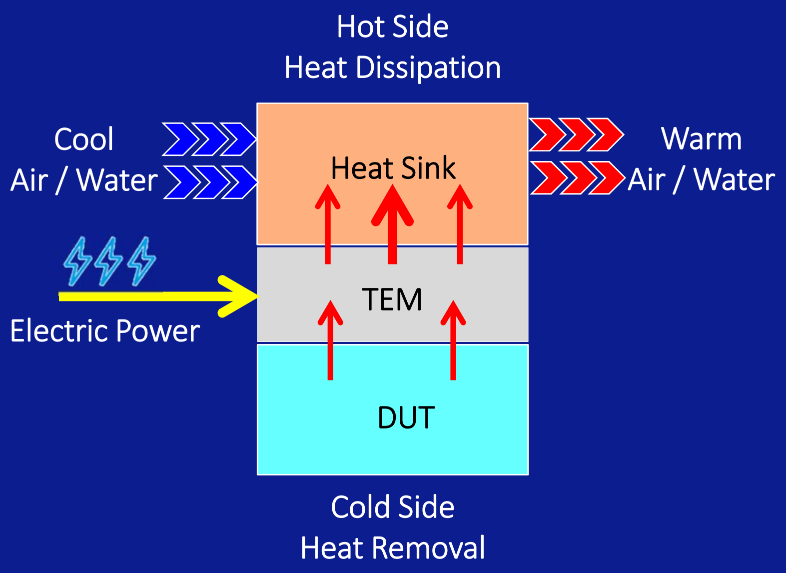
Objective: to develop a scalable active thermal control solution for

a. -40°C to 150°C test temperature.
b. Supports 100s of DUTs (a massively parallel system).
c. Each DUT operates independently (active control per DUT).

Available cooling technologies for us.

a. Thermoelectric cooling
b. Liquid cooling

Thermoelectric Cooling Scalability

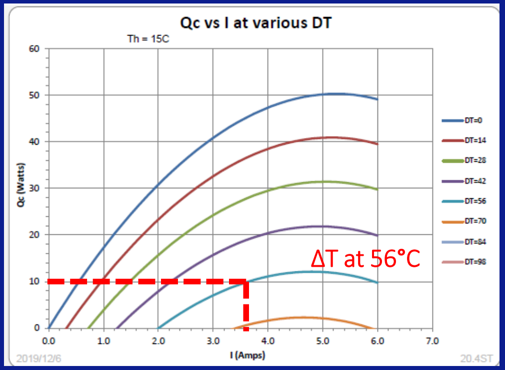


Note: TEM : Thermoelectric Module
DUT : Device Under Test

Hot side power = Cold side power + electrical power

Thermoelectric Cooling Scalability

Case Study

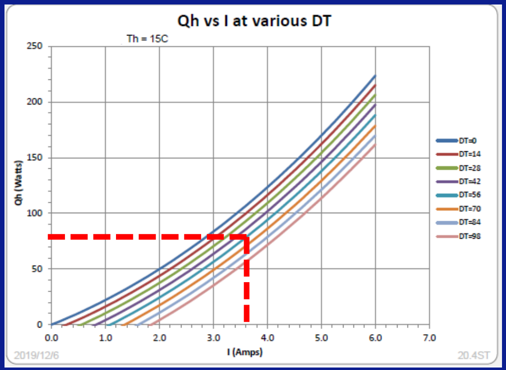


10W
Cooling

ΔT at 56°C

3.6A

80W
Heat



3.6A

Number of DUT	Cooling Power	Electric Power	Total Heat Dissipation
1	10W	70W	80W
50	500W	3,500W	4,000W
100	1,000W	7,000W	8,000W
300	3,000W	21,000W	24,000W

Thermoelectric Cooler Spec

Number of Stage : 2
Dimension : 40x40mm
Hot Side Temperature : 15°C (with Water cool)
Cold Side Temperature : -40°C

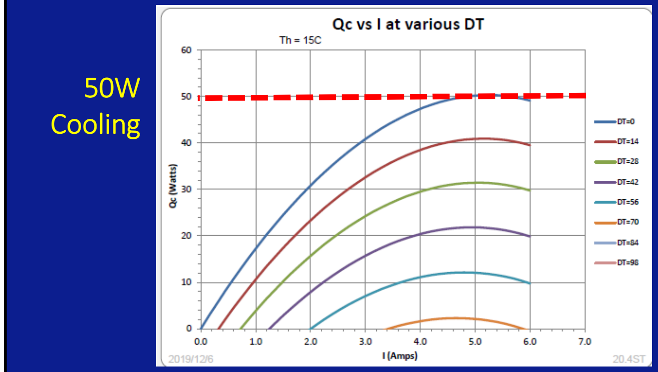
COP @ -40°C

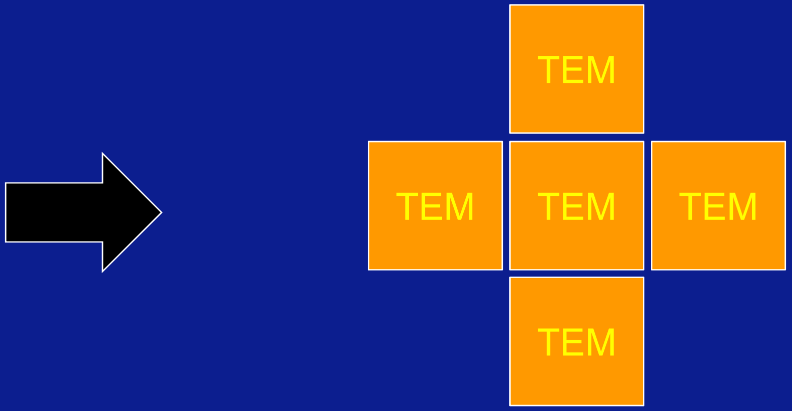
10W / 70W = 0.1428

COP: Coefficient of Performance

Thermoelectric Cooling Scalability

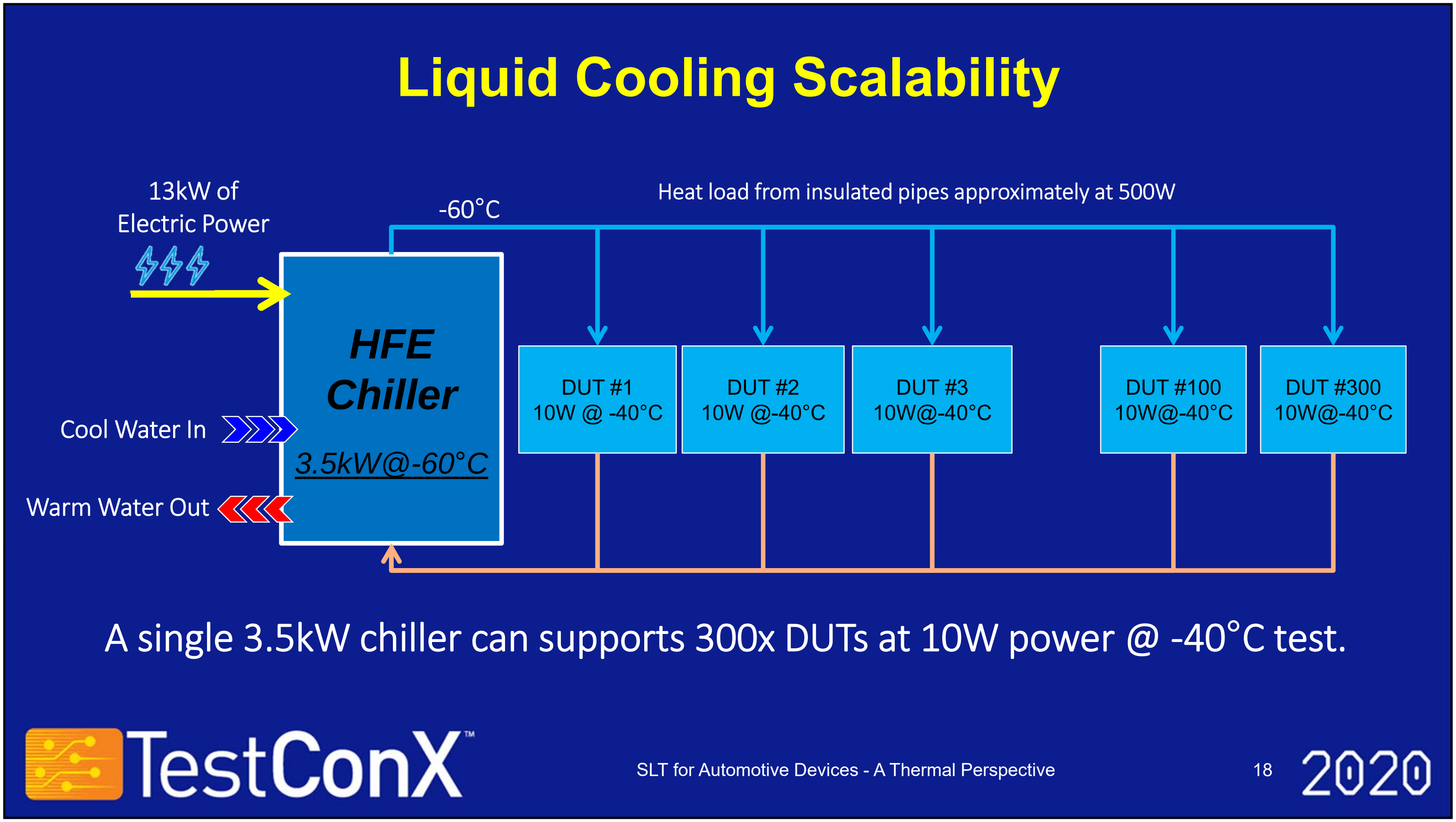
What if we want to support higher power, let's say 50W?





Single TEM is unable to reach the ΔT that we need for 50W DUT power.

5x TEM on each DUT are required, 5x more power, 5x larger in area.



Liquid Cooling Scalability

13kW of Electric Power

-60°C

Heat load from insulated pipes approximately at 500W

HFE Chiller

3.5kW@-60°C

Cool Water In

Warm Water Out

DUT #1 10W @ -40°C

DUT #2 10W @-40°C

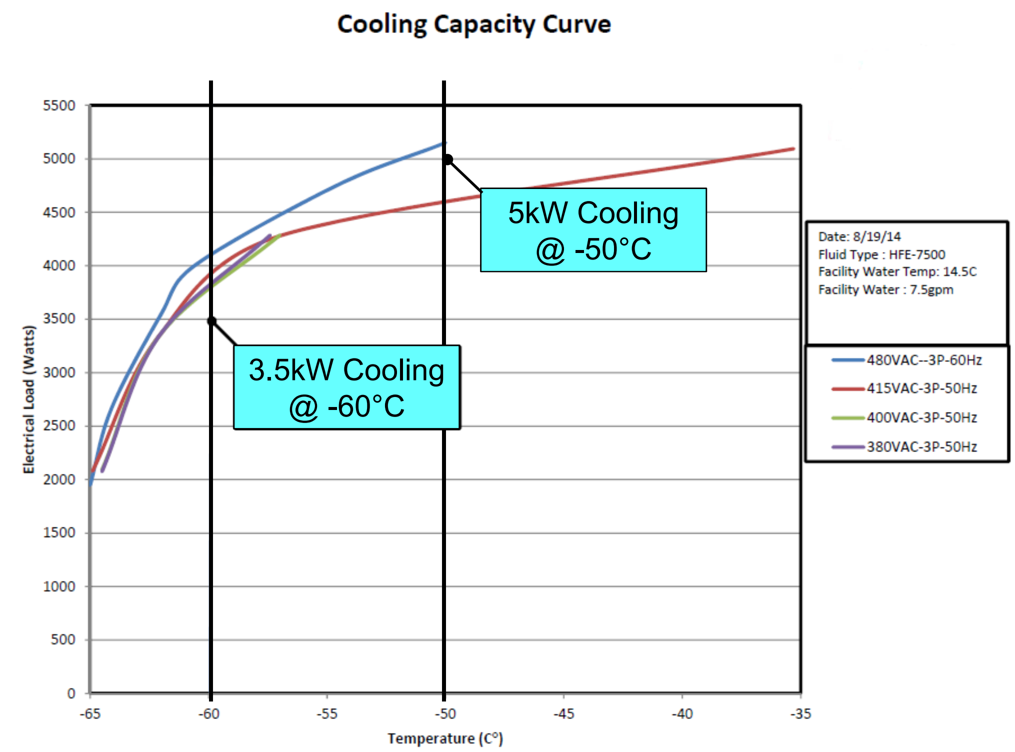
DUT #3 10W@-40°C

DUT #100 10W@-40°C

DUT #300 10W@-40°C

A single 3.5kW chiller can supports 300x DUTs at 10W power @ -40°C test.

Liquid Cooling Scalability – Chiller Capability



5kW Cooling @ -50°C

3.5kW Cooling @ -60°C

Date: 8/19/14
Fluid Type : HFE-7500
Facility Water Temp: 14.5C
Facility Water : 7.5gpm

<u>HFE Chiller Spec</u>

Process Fluid : NOVEC 7500
Heat Removal : Chilled Water
Cooling Capacity : 3.5kW @ -60°C
Full Load Electric Power : 13kW @ 480VAC, 60Hz

<u>Efficiency @ -60°C</u>

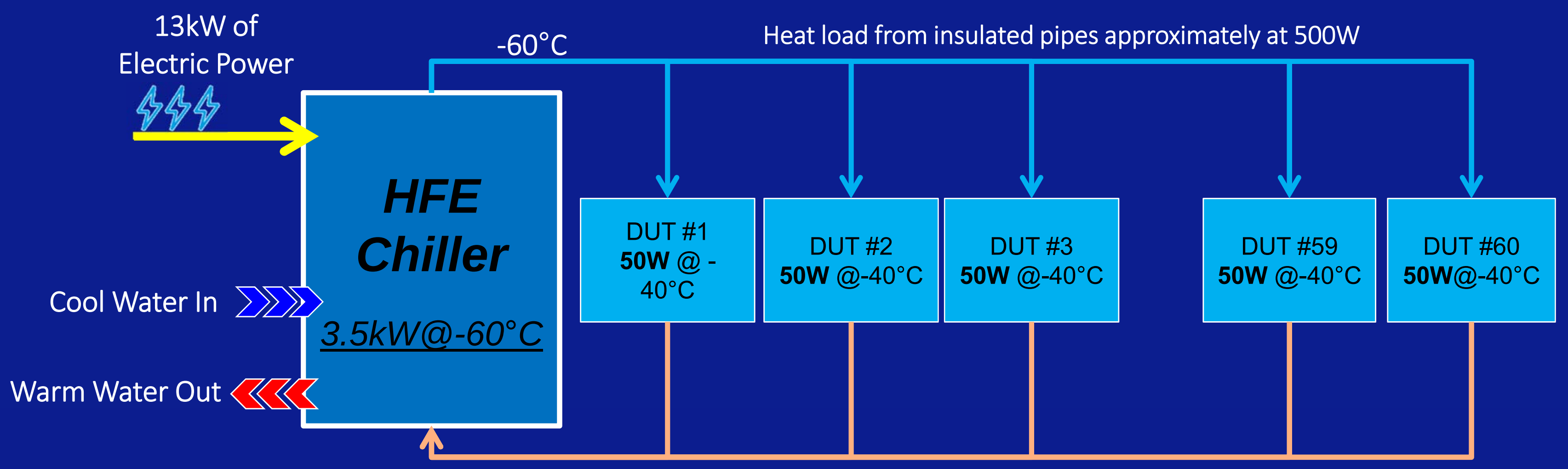
3.5kW / 13.5kW = 0.2592

<u>Efficiency @ -50°C</u>

5kW / 13.5kW = 0.37

Liquid Cooling Scalability

What about 50W or beyond?



13kW of
Electric Power

-60°C

Heat load from insulated pipes approximately at 500W

HFE Chiller

3.5kW@-60°C

Cool Water In

Warm Water Out

DUT #1
50W @ -40°C

DUT #2
50W @-40°C

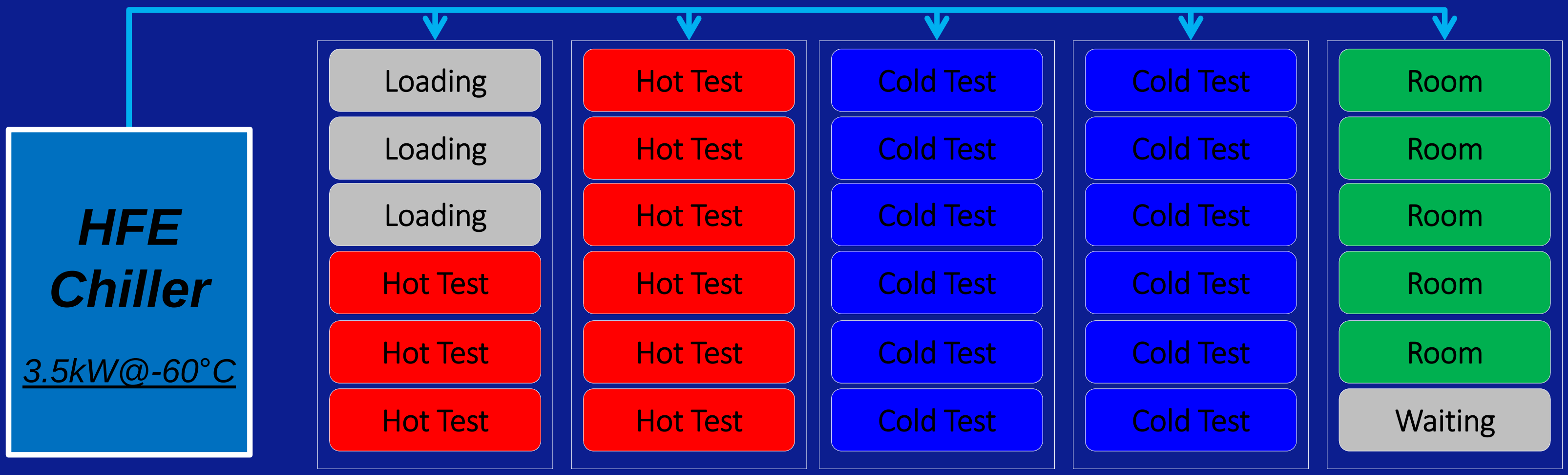
DUT #3
50W @-40°C

DUT #59
50W @-40°C

DUT #60
50W@-40°C

The same setup can support 60x DUT at 50W power @ -40°C without needing to change the hardware.

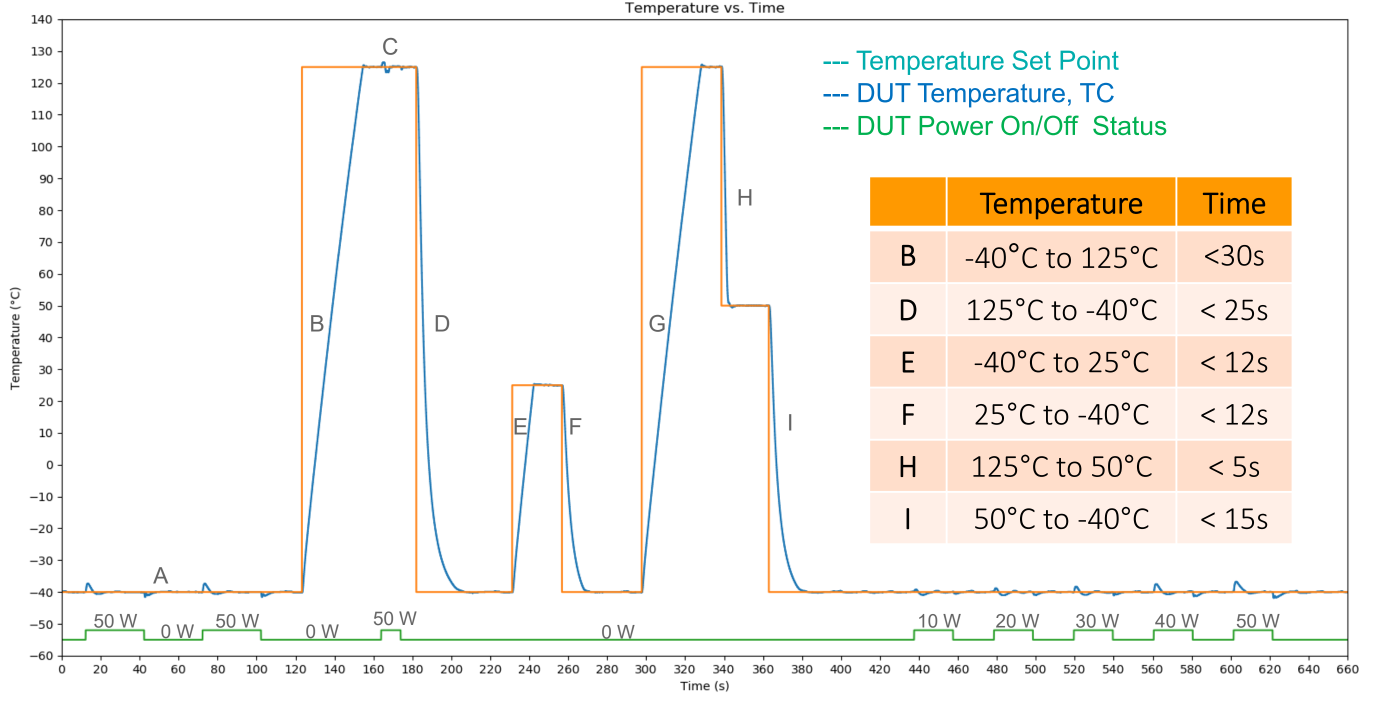
Liquid Cooling Scalability



Loading	Hot Test	Cold Test	Cold Test	Room
Loading	Hot Test	Cold Test	Cold Test	Room
Loading	Hot Test	Cold Test	Cold Test	Room
Hot Test	Hot Test	Cold Test	Cold Test	Room
Hot Test	Hot Test	Cold Test	Cold Test	Room
Hot Test	Hot Test	Cold Test	Cold Test	Waiting

When CTUs run tri-temp test, each CTU starts at different times. Only partial of the CTUs are in peak consumption of cooling power at one time. Hence a single chiller can support a large number of cells yet maintaining its best thermal control performance.

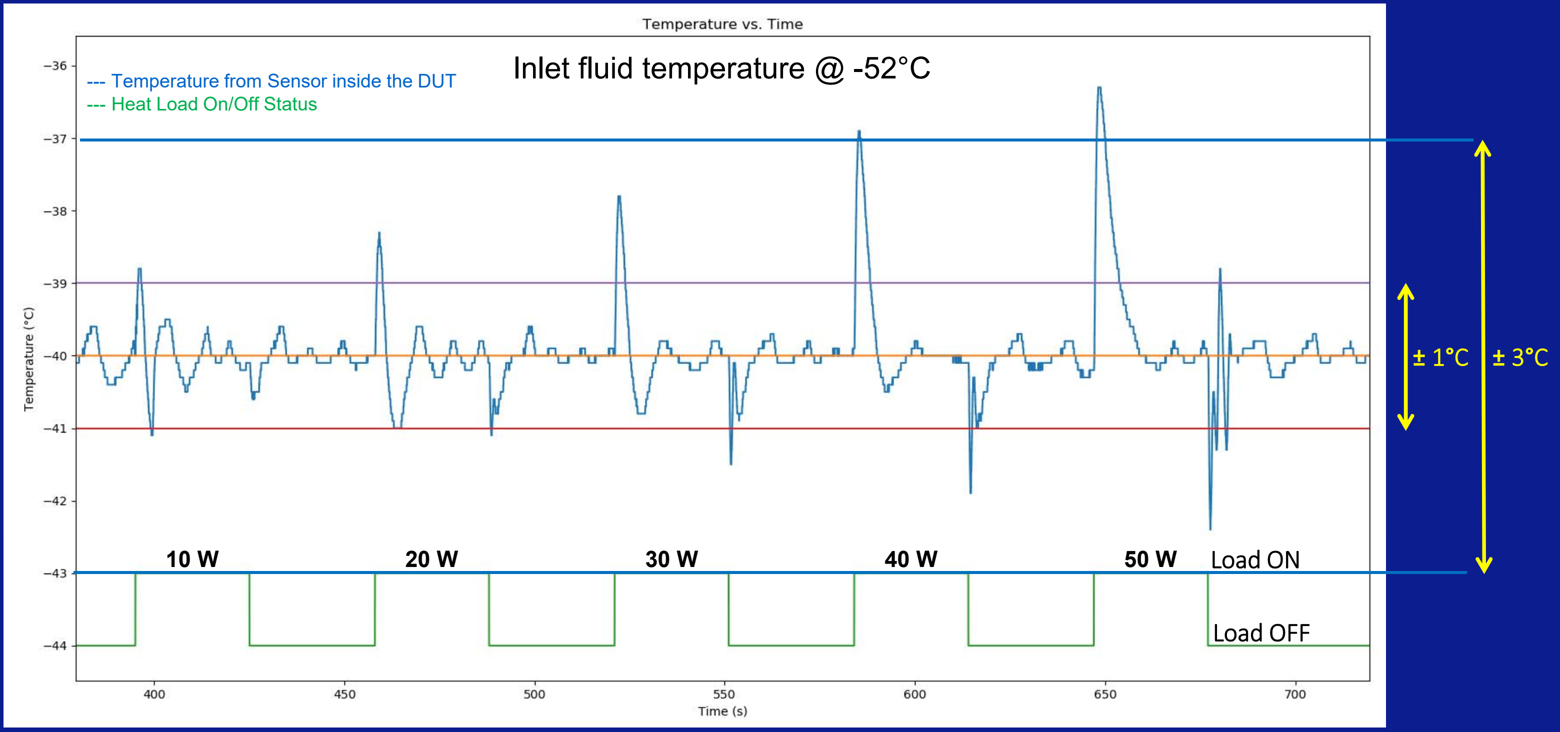
Test Data – Liquid Cooling



	Temperature	Time
B	-40°C to 125°C	<30s
D	125°C to -40°C	< 25s
E	-40°C to 25°C	< 12s
F	25°C to -40°C	< 12s
H	125°C to 50°C	< 5s
I	50°C to -40°C	< 15s

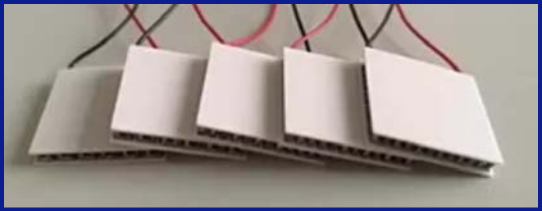
Note: Above data is the test result specific to the test setup used in the test. The performance in production setup may vary depends on the design and other conditions

Test Data – Liquid Cooling



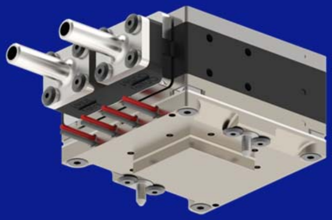
Thermal Solution Scalability – Size

Thermoelectric Cooling

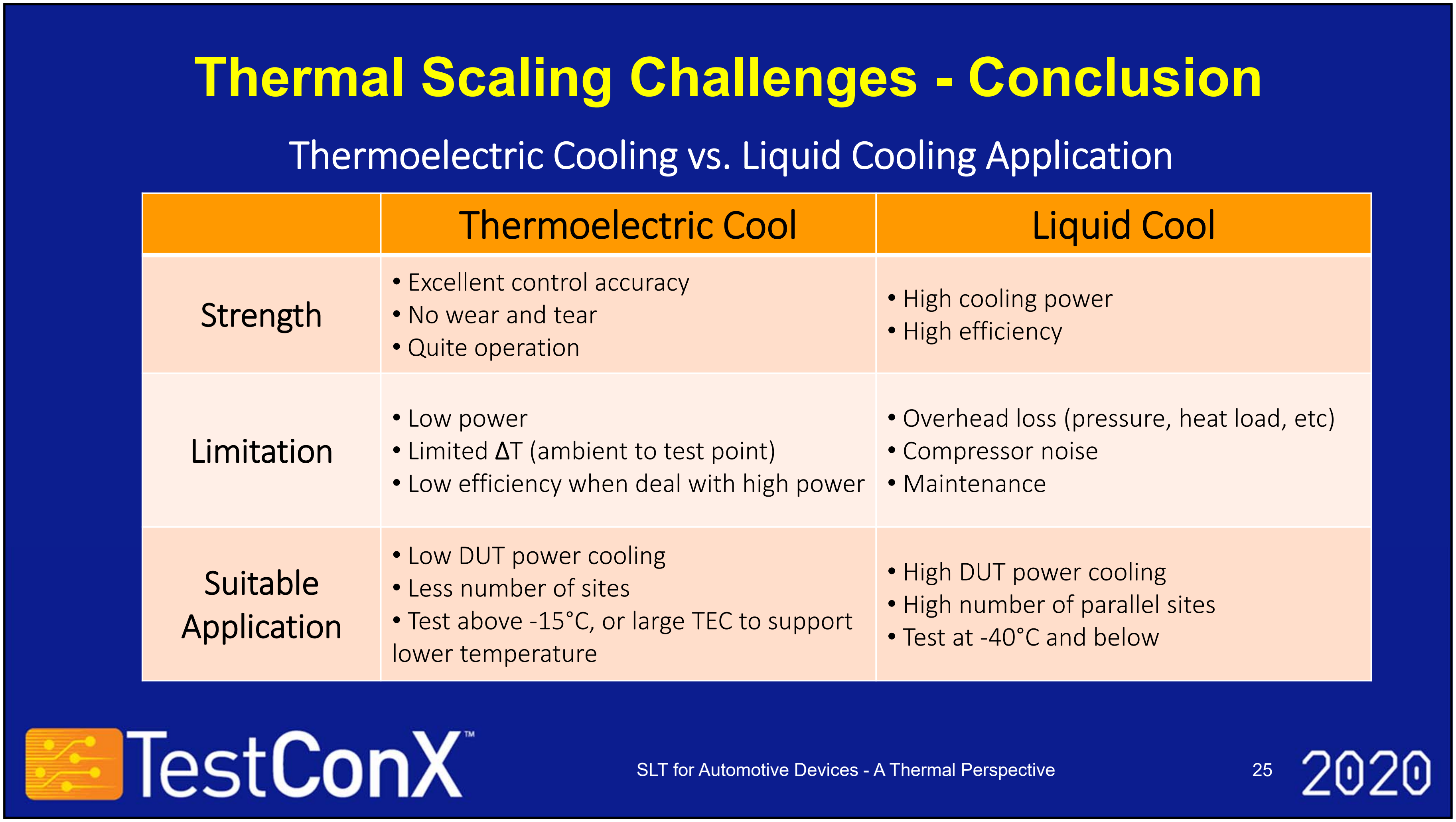


To bring the DUT case temperature to -40°C @ 50W DUT Power, we use 5x TEM of 50x50x7mm with water cooling.

Liquid Cooling



To bring the DUT Junction Temperature to -40°C @ 50W DUT Power, we use a cold plate 50x50x10mm with -60°C HFE supply.



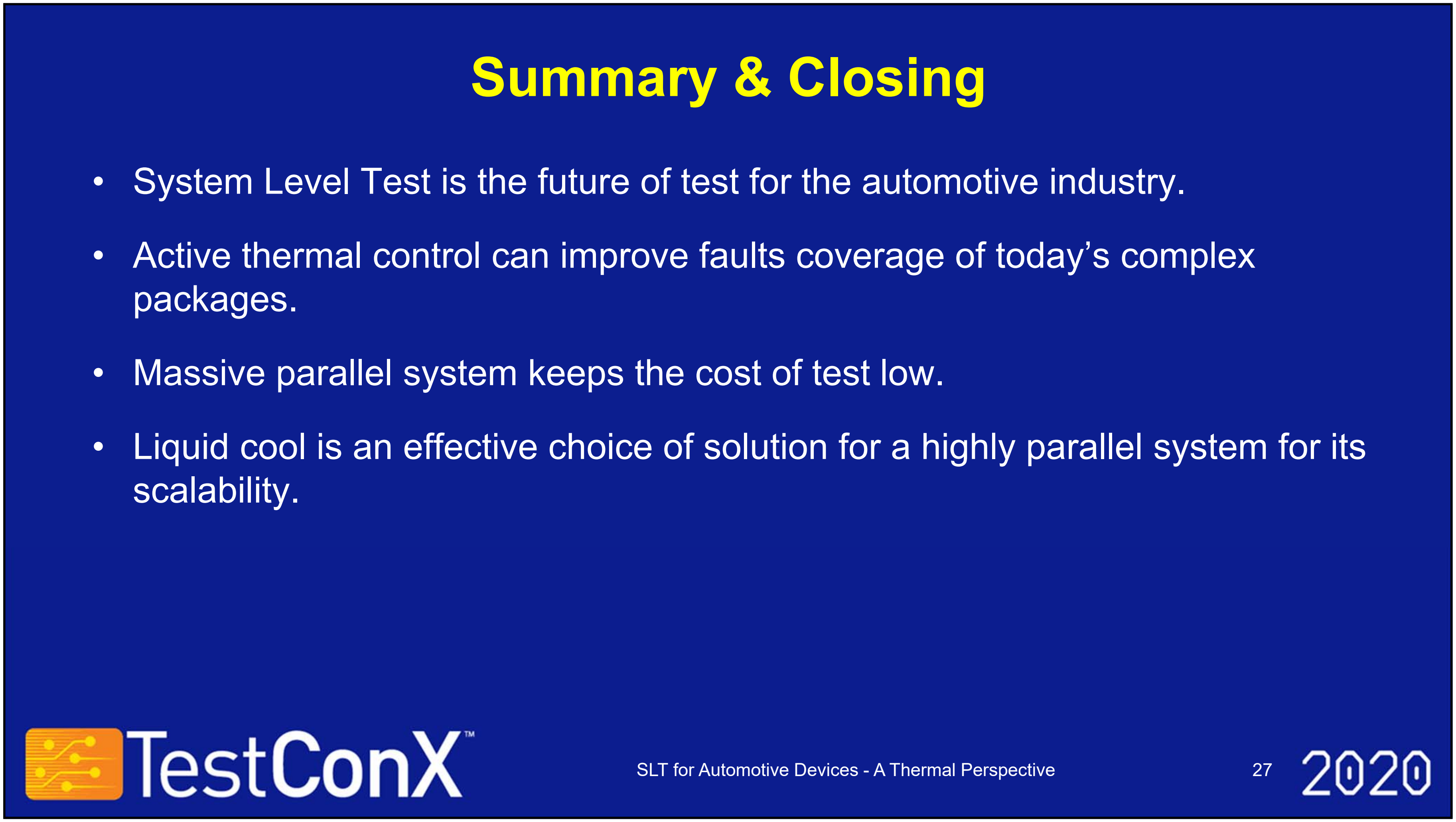
Thermal Scaling Challenges - Conclusion

Thermoelectric Cooling vs. Liquid Cooling Application

	Thermoelectric Cool	Liquid Cool
Strength	• Excellent control accuracy • No wear and tear • Quite operation	• High cooling power • High efficiency
Limitation	• Low power • Limited ΔT (ambient to test point) • Low efficiency when deal with high power	• Overhead loss (pressure, heat load, etc) • Compressor noise • Maintenance
Suitable Application	• Low DUT power cooling • Less number of sites • Test above -15°C, or large TEC to support lower temperature	• High DUT power cooling • High number of parallel sites • Test at -40°C and below

Scalable Thermal Solution: Current and Future Developments

- Challenges managed
  - Compact solution allowing modular, independent, and asynchronous operation.
  - Scalable platform with extreme low temperature testing capability targeting automotive requirements.
  - Centralized infrastructure to support test with higher DUT power.
- Challenges ahead & future development plan
  - More and more DUT power!
  - Wider temperature coverage and faster temperature swing.
  - Temperature control for complex devices e.g. multi-zone temperature control
  - Further enhance chiller’s efficiency.



Summary & Closing

- System Level Test is the future of test for the automotive industry.
- Active thermal control can improve faults coverage of today’s complex packages.
- Massive parallel system keeps the cost of test low.
- Liquid cool is an effective choice of solution for a highly parallel system for its scalability.

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