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DOE 2009 Thermoelectrics Applications Workshop

Tunable LAST Thermoelectric Properties for Generator Applications

Charles Cauchy

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Presentation Contents

- Power generator applications and temp. conditions (variable)
- “Dials” of LAST material (compositional and processing)
- LAST A, B, & C thermoelectric parameters
- Tunable LAST parameters and how the application affects what “Dials” to turn
- Models of LAST modules in applications
- Segmentation “Dial” added to tune material for application
- Optimum materials developed for three examples of hot-side and cold-side temperatures

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TE Generator Applications

Generator Examples

- Diesel Engine Waste Heat Recovery
- Automotive Gasoline Engine Catalytic Converter Harvesting
- Silent APU
- SOFC/TE Power Systems
- Self-powered Sensors
- Industrial Processing Controls
- Self-powered Furnaces
- Man-portable, Multi-fueled Power Devices
- CPV’s

Thermoelectric Power Generation

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Temperatures

Wide Range of Temperatures

Hot Side Temps.

Engine & Catalytic	300 – 900+ºC
APU (burner)	400 - 700ºC
SOFC	400 - 800ºC
Sensor Inputs	0 - 500ºC
Industrial Processes	0 – 1000+ºC
Self-powered Furnaces	250 - 450ºC
Portable Power	175 - 500ºC

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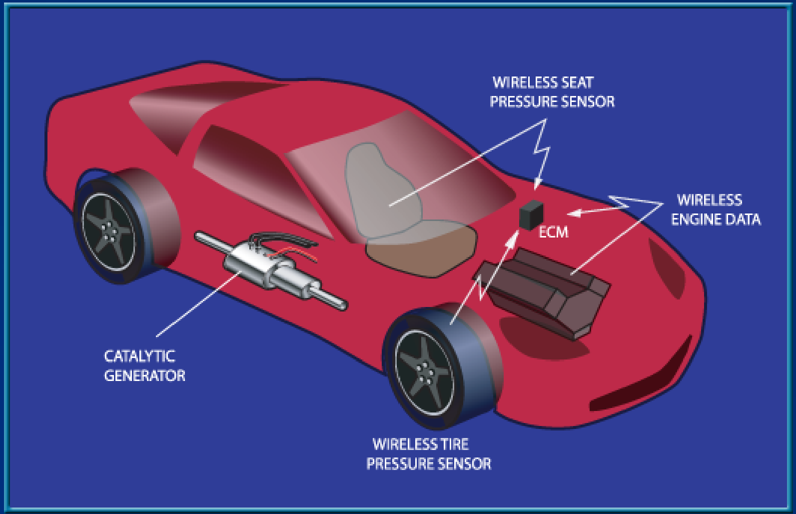
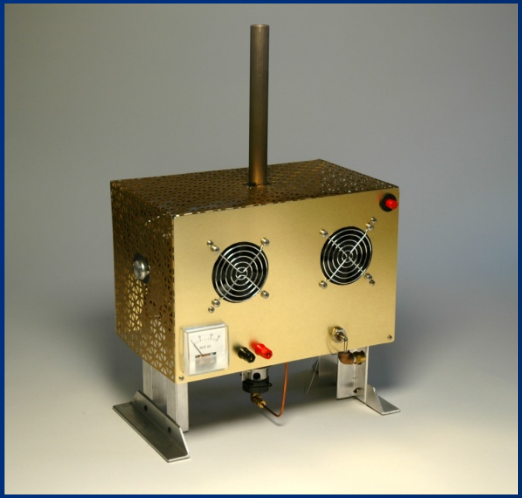
Applications Drive Use Temperature

CHP Systems



Automotive Applications

Small Remote Power



APU's

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The Right TE Material for the Application

With the wide range of applications that operate under different temperatures, thermoelectric materials that can operate under these different conditions and ΔT's would be useful. In research developing the LAST(T) family of materials, it was found that even within this family, useful property variations can be developed by changing critical parameters.

Other thermoelectric materials such as skutterudites, TAGS, PbTe, SiGe, etc. or combinations of materials can also accommodate a wide range of temperature and ΔT's. The following graphs will indicate that (LAST), utilizing the dials available with the material and processing techniques, can provide results useful in several temperature regimes.

LAST Material Tunability

Several Factors Influence Performance of Material

Potential for Customization of Material Properties
For Specific Temperature

Composition

Powder Processing

Particle size
Shape
Distribution

Pressing

Density

Heat Treating

Density
Oxygen
Strength

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LAST Materials

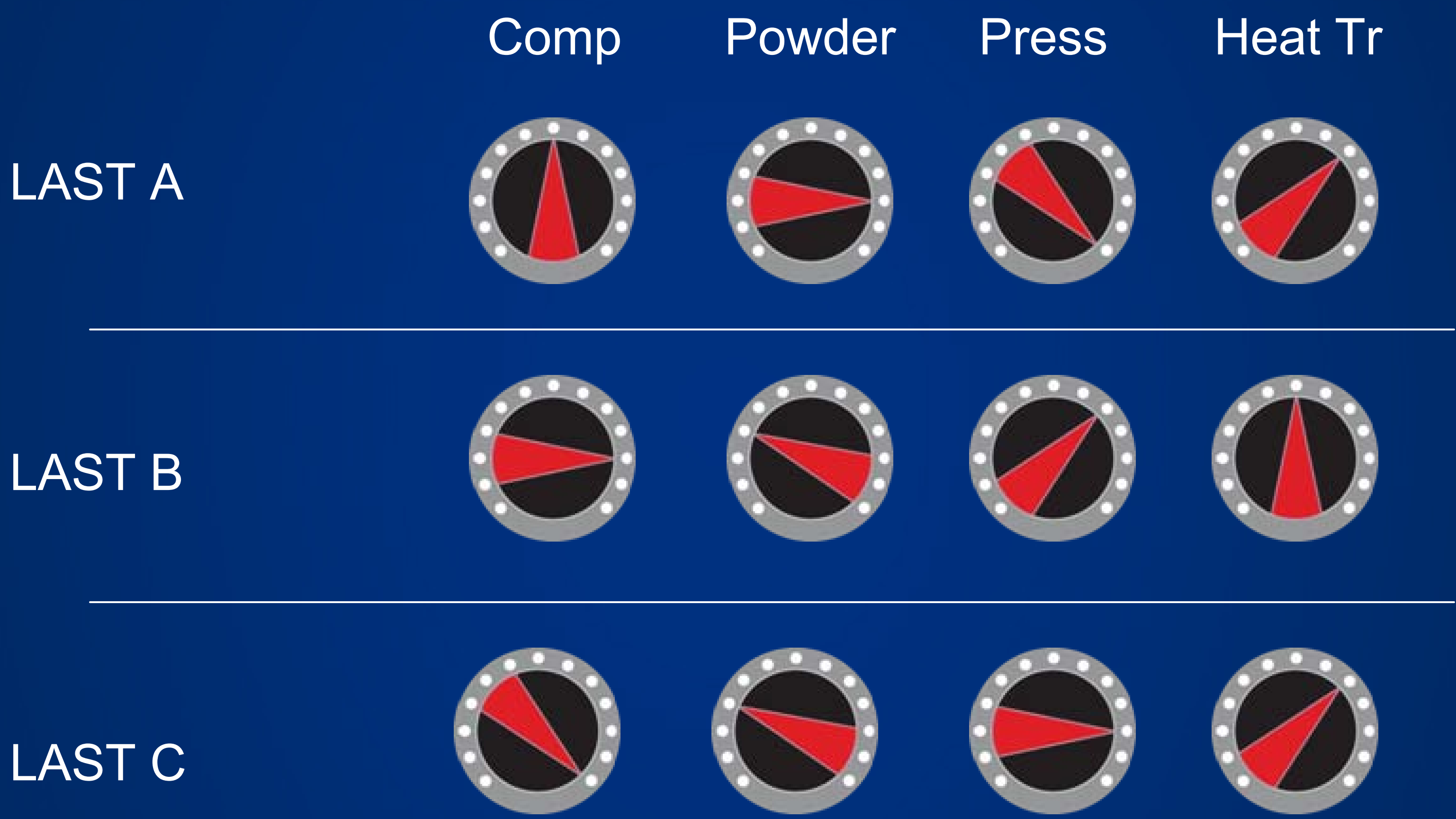
Three Variations of LAST

In the continuing development of the LAST material it was found that by varying different parameters, the properties of the materials changed. Analysis of these changes gave perspective on designing outcomes.

Though many variations have been developed, for the sake of clarity, three LAST materials are highlighted to indicate the tunability of the material and some possible use temperature environments in which the different LAST materials may be useful both alone and in combination with bismuth telluride.

LAST Materials

In development of the LAST material it was found that by varying different parameters, the properties of the materials changed.



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LAST Materials

Compostions:

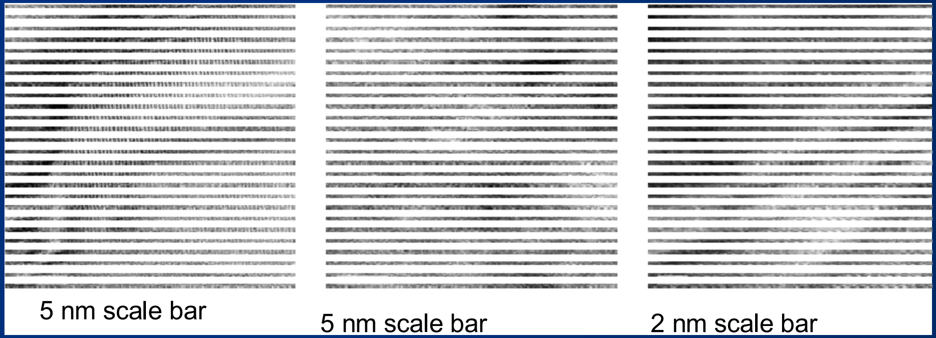
Base n-type LAST Composition:

$Pb_mSbAgTe_{1+m}$

Base p-type LASTT Composition:

$Pb_mSbAgSn_mTe_{11+m}$

Nanostructures Inherent in material independent of processing



Material Processing

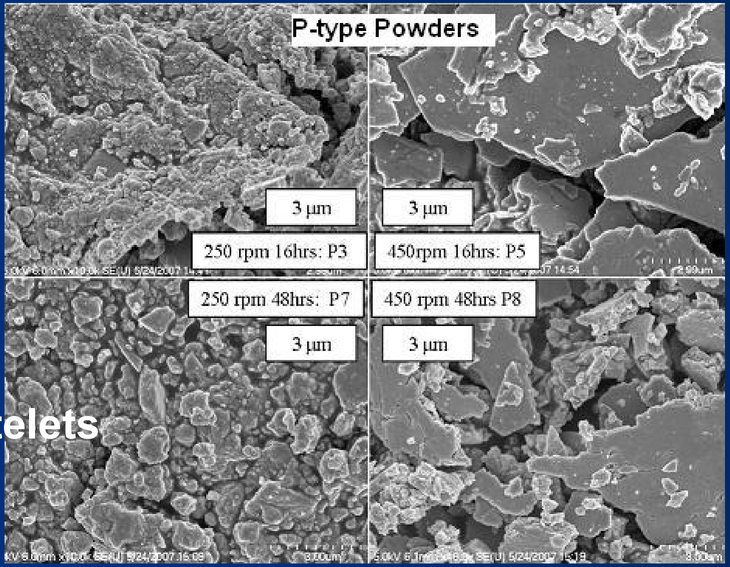
Powder Size and Shape

Powder size and shape can affect the thermoelectric properties of the materials.

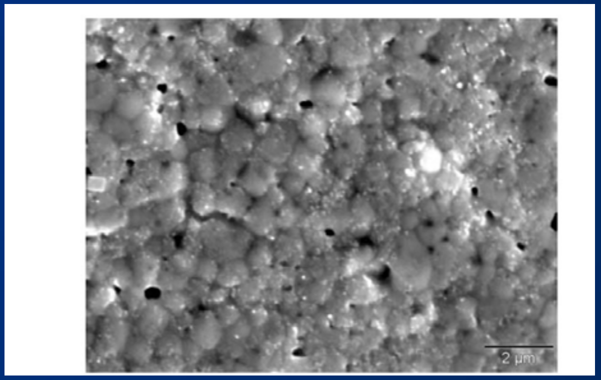
Other properties:

- Strength
- Bonding affinity
- Ability to cut

Platelets



Spheres



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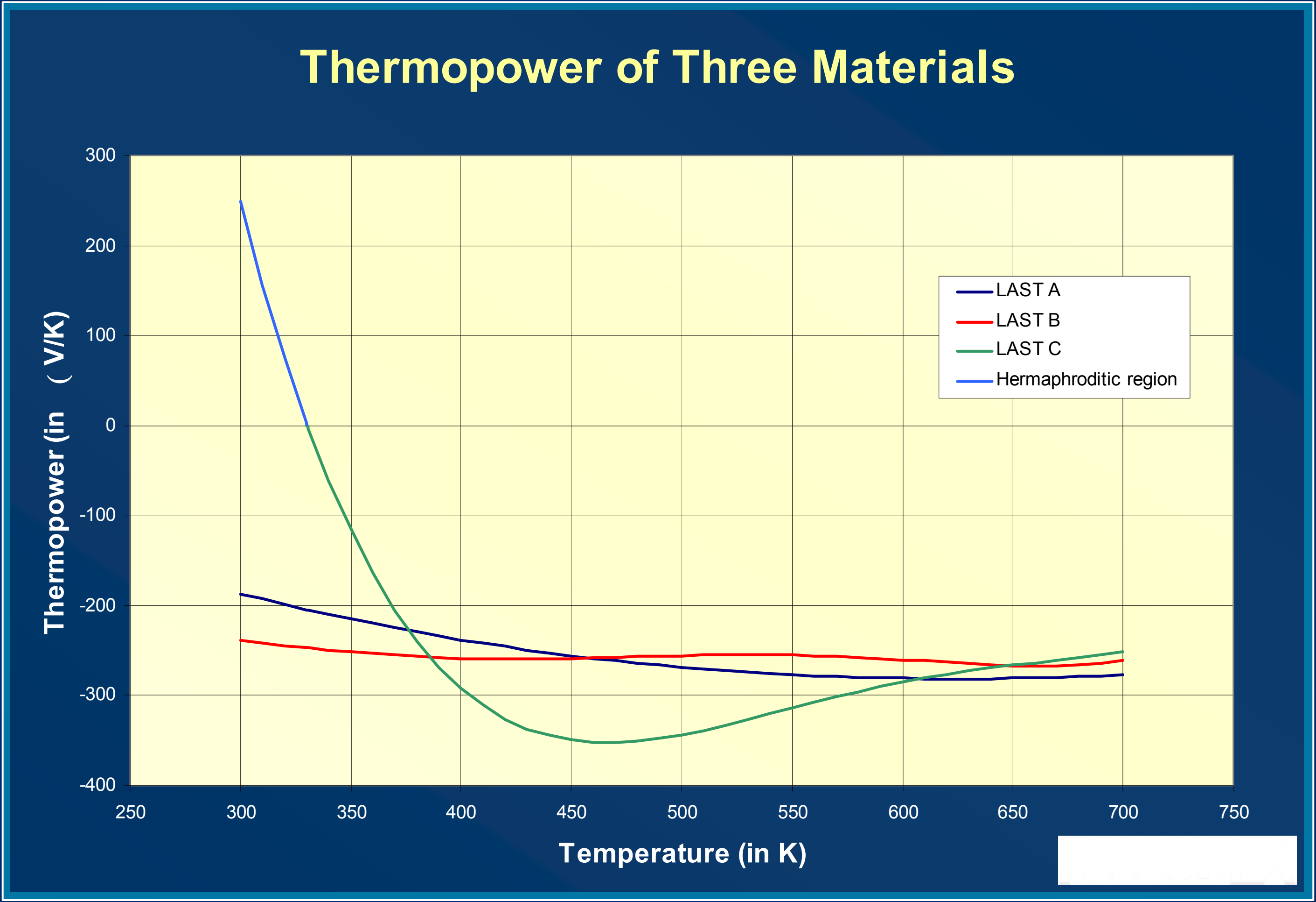
Thermoelectric Properties



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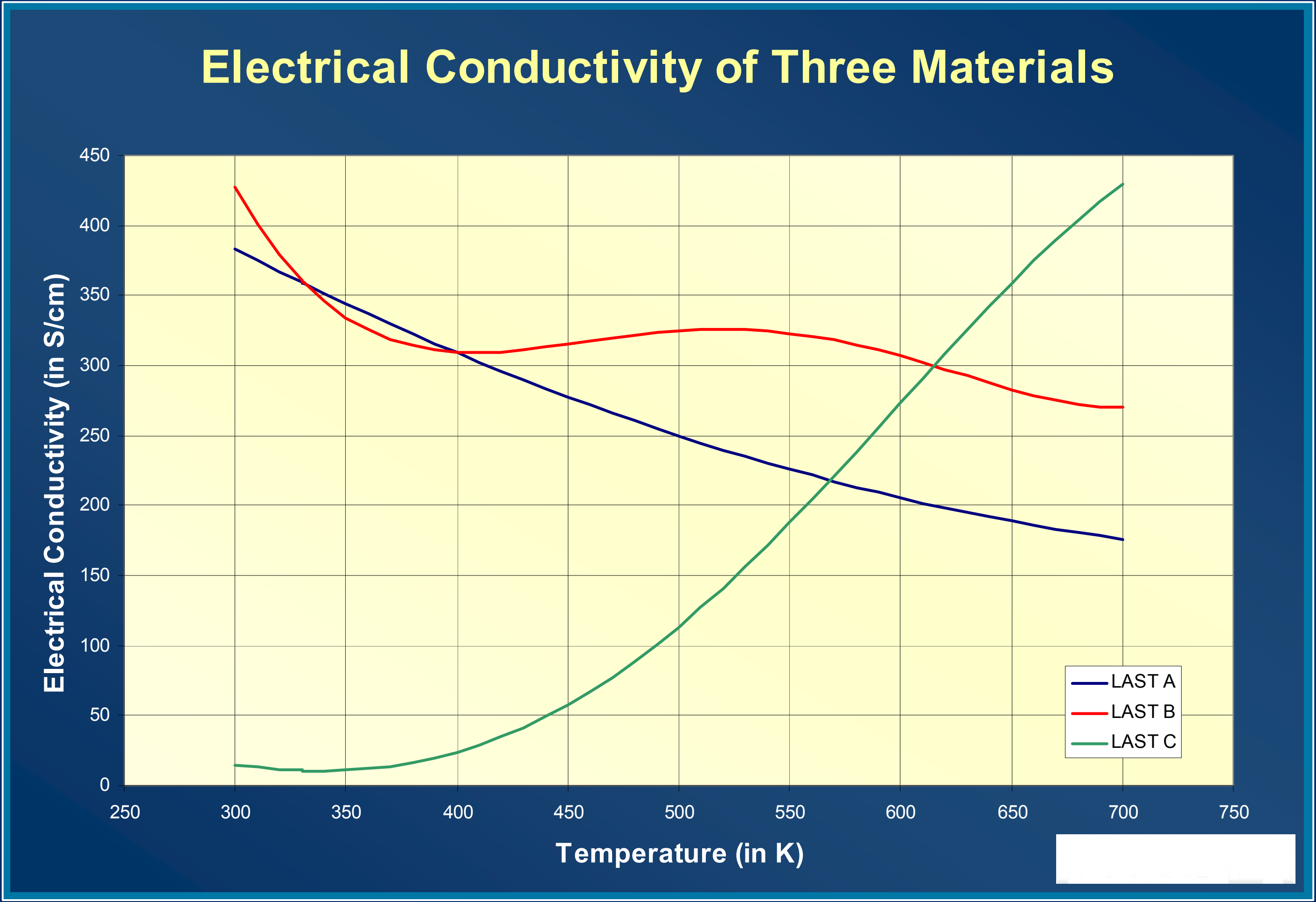
Thermoelectric Properties



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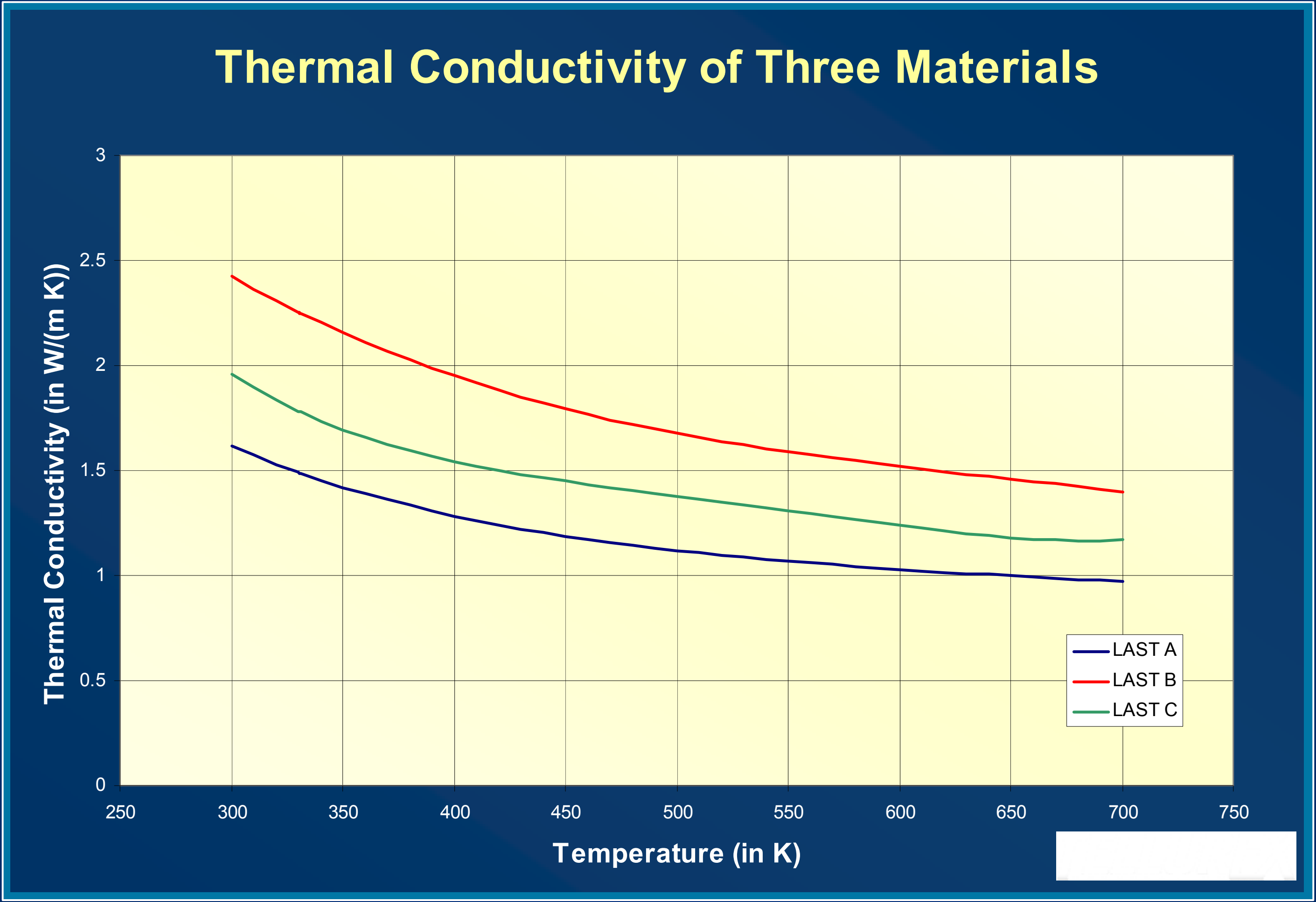
Thermoelectric Properties



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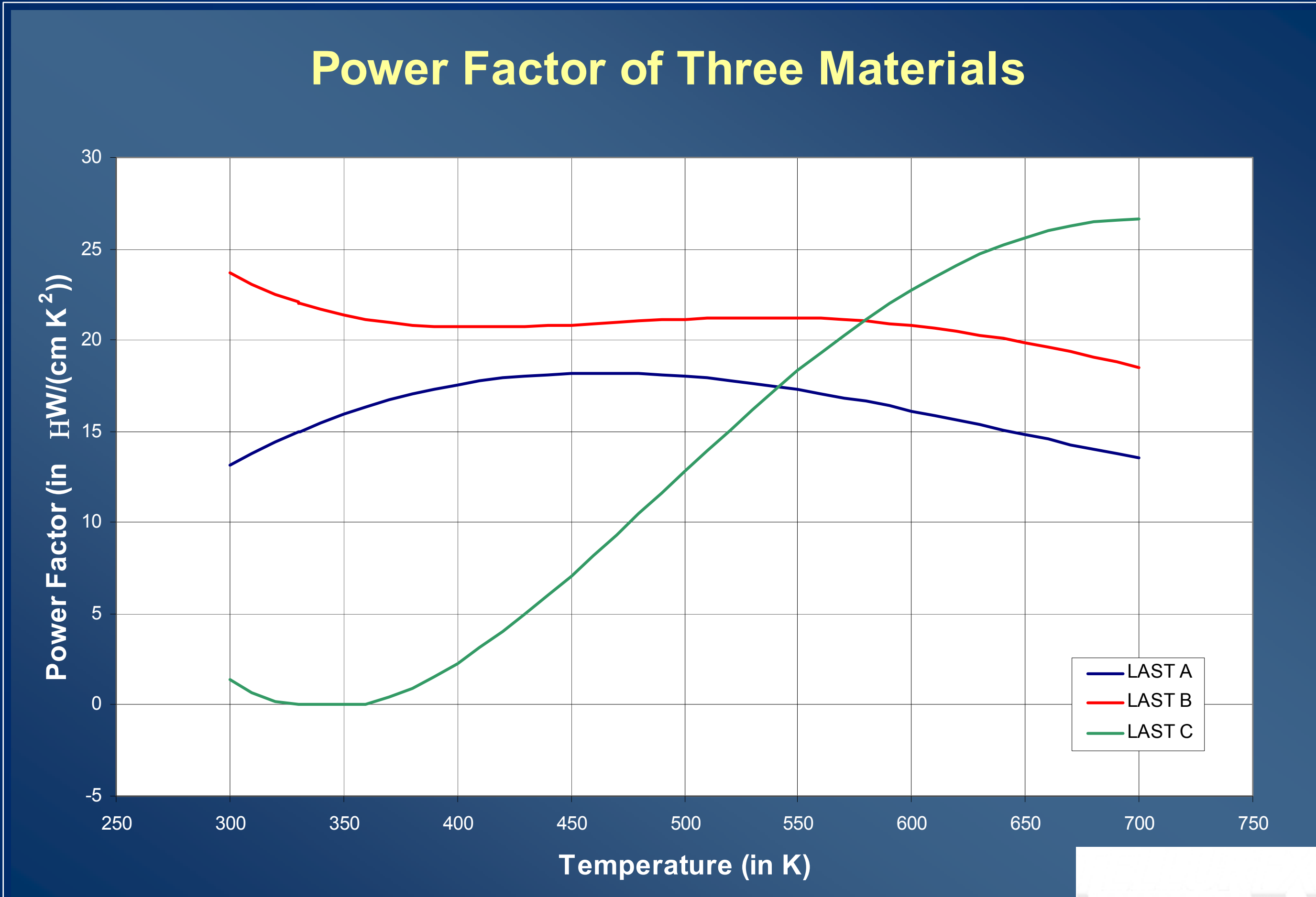
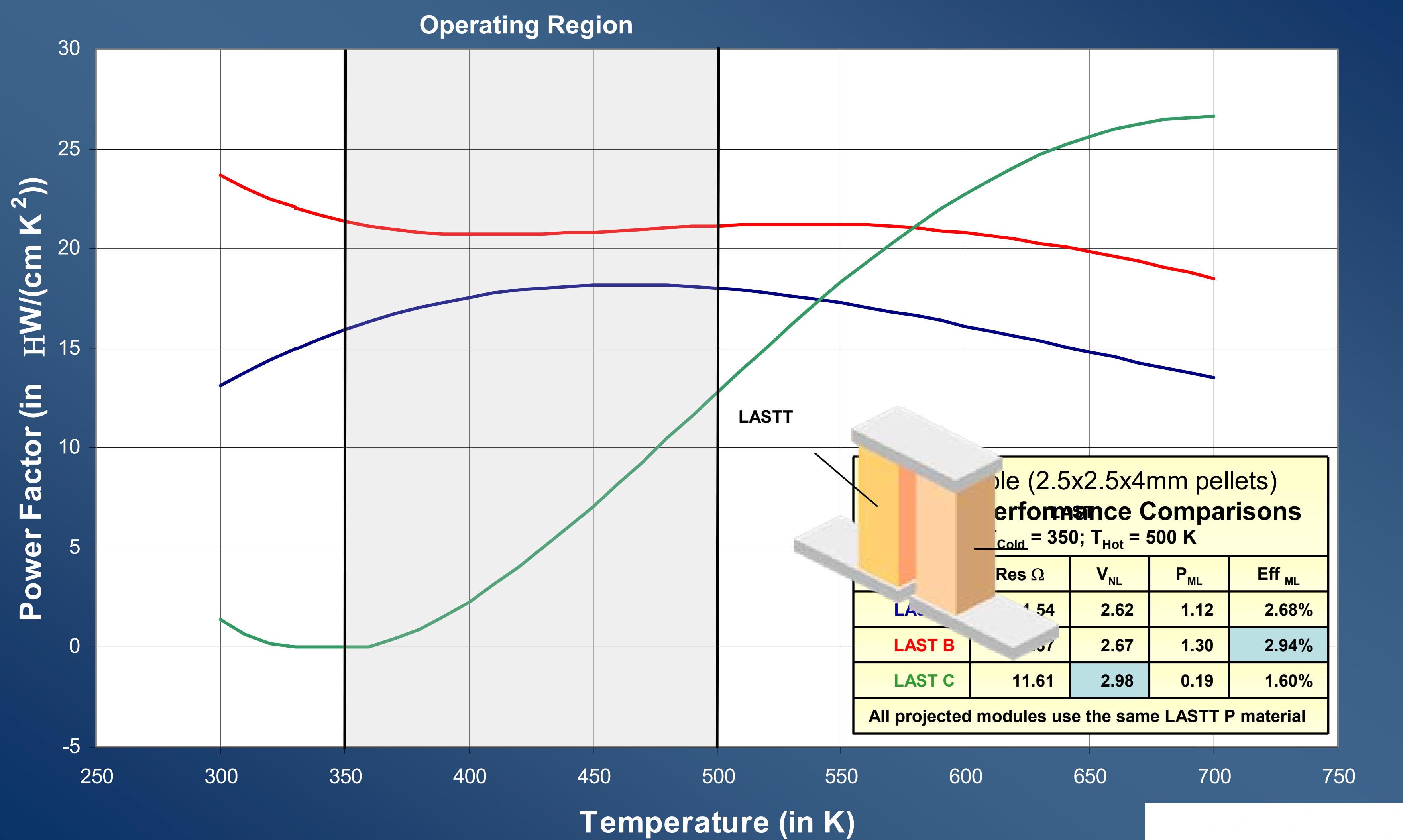
Thermoelectric Properties



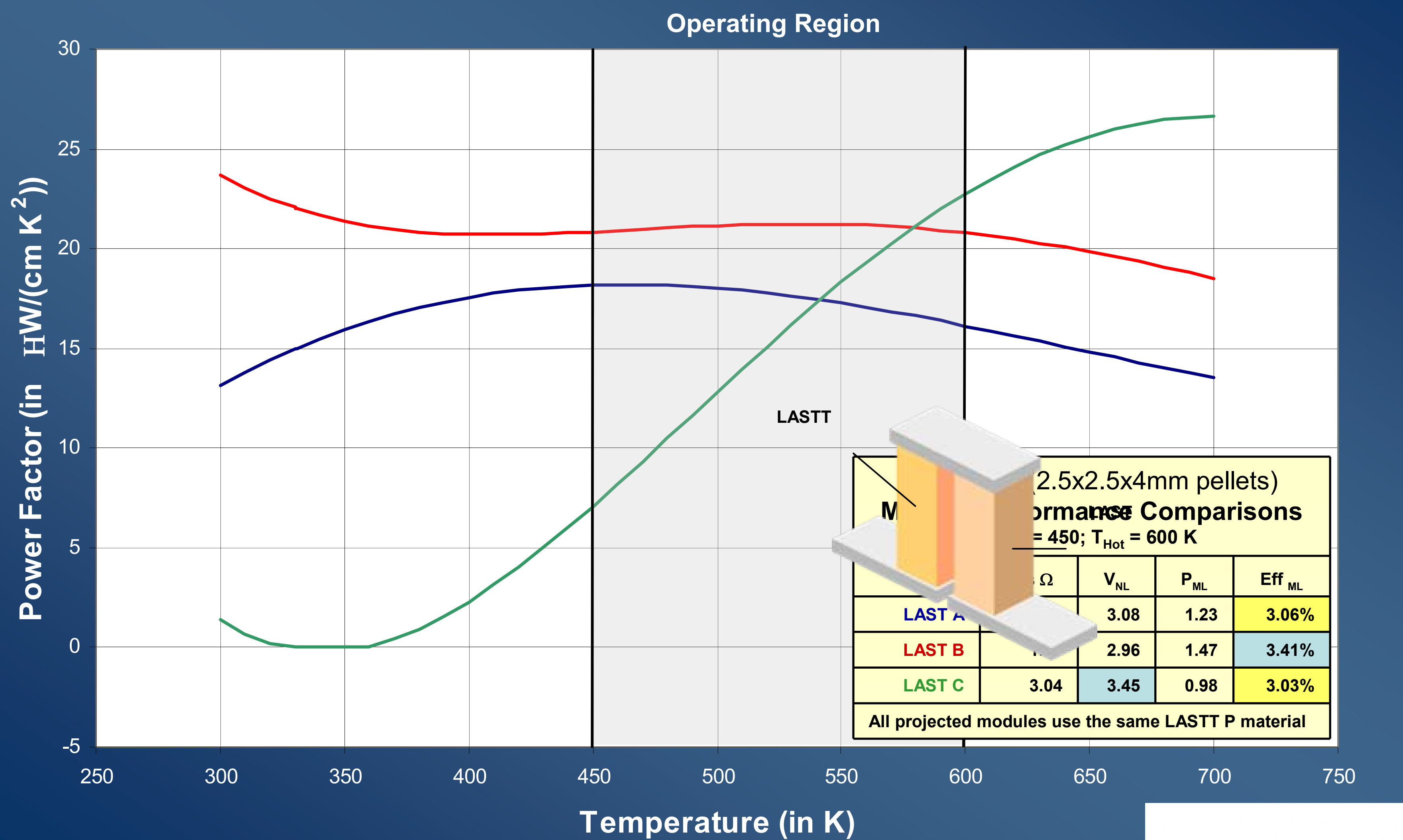
Module Performance

Power Factor of Three Materials



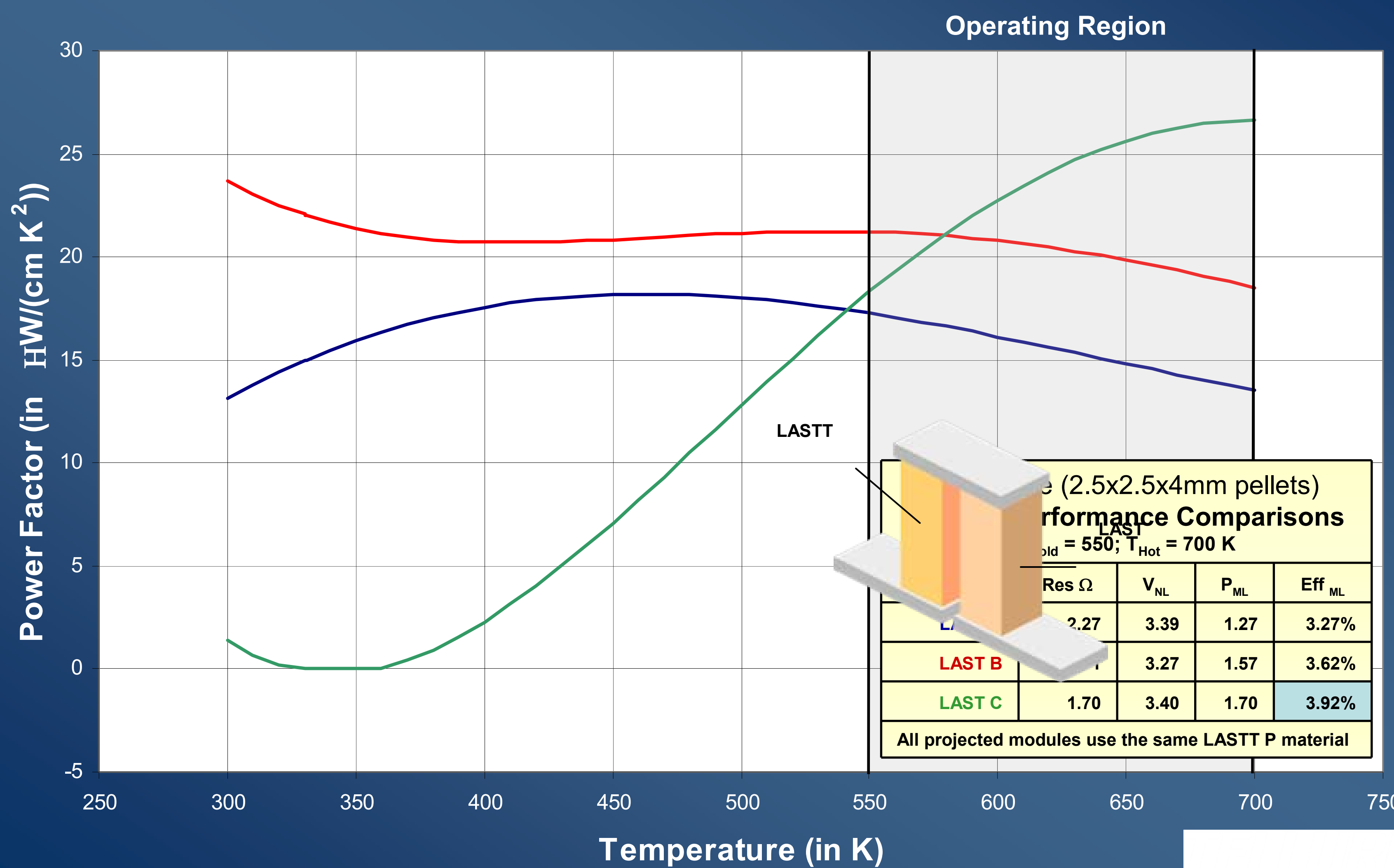
Module Performance

Power Factor of Three Materials



Module Performance

Power Factor of Three Materials

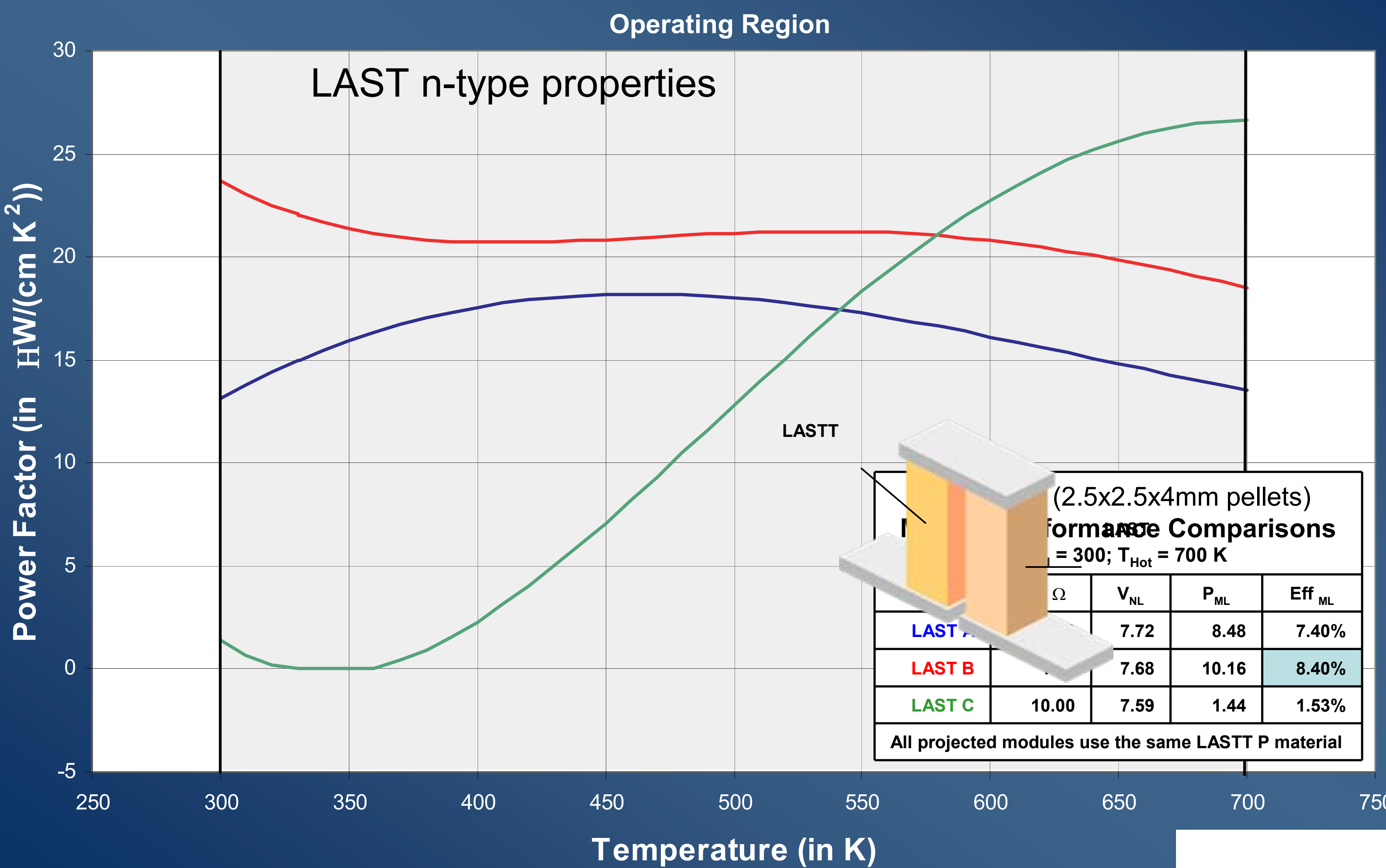


e (2.5x2.5x4mm pellets)
rformance Comparisons
old = 550; T_{Hot} = 700 K

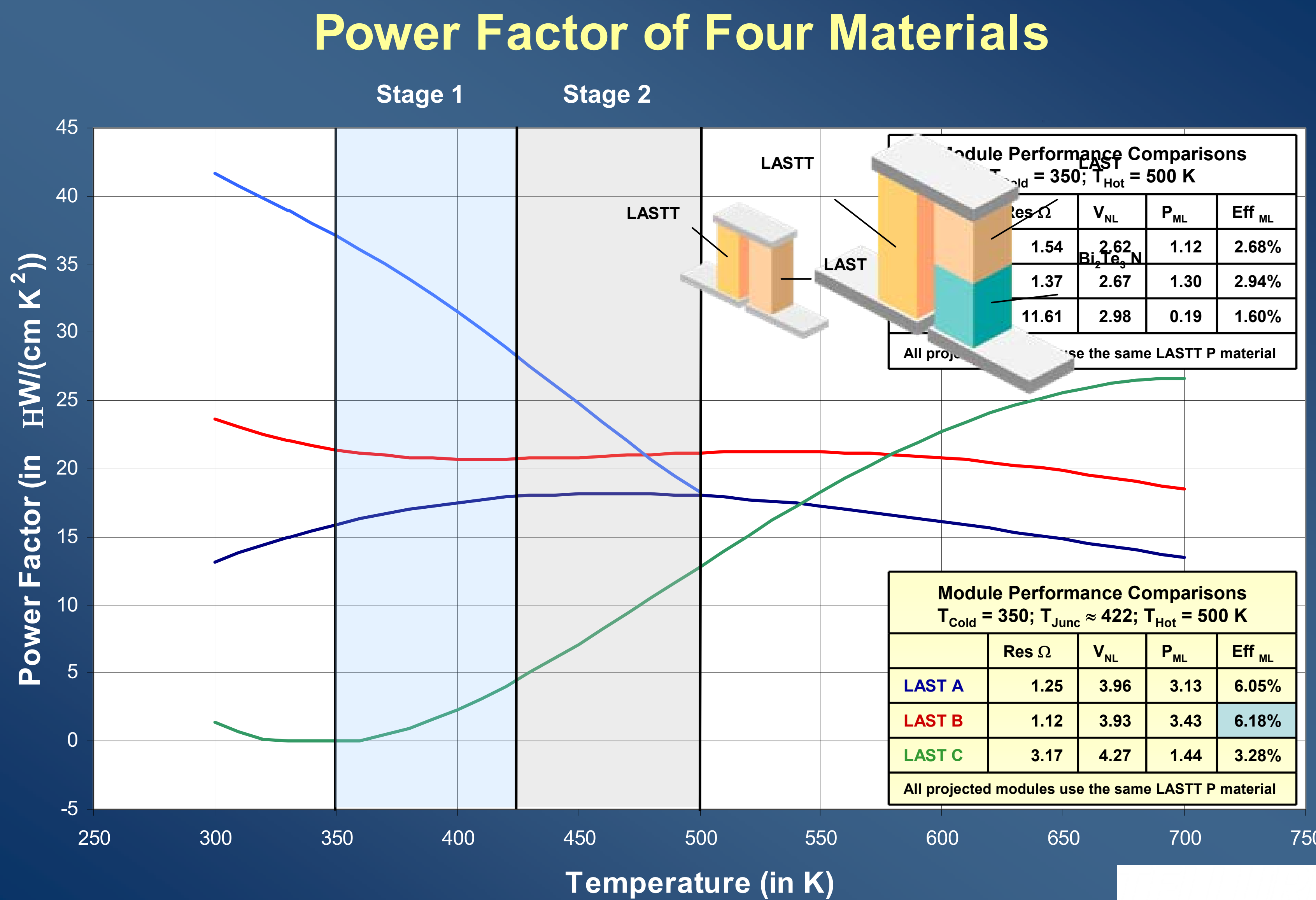
	Res Ω	V_{NL}	P_{ML}	Eff $_{ML}$
L[illegible]	2.27	3.39	1.27	3.27%
LAST B	[illegible]	3.27	1.57	3.62%
LAST C	1.70	3.40	1.70	3.92%
All projected modules use the same LASTT P material				

Module Performance

Power Factor of Three Materials



Module Performance



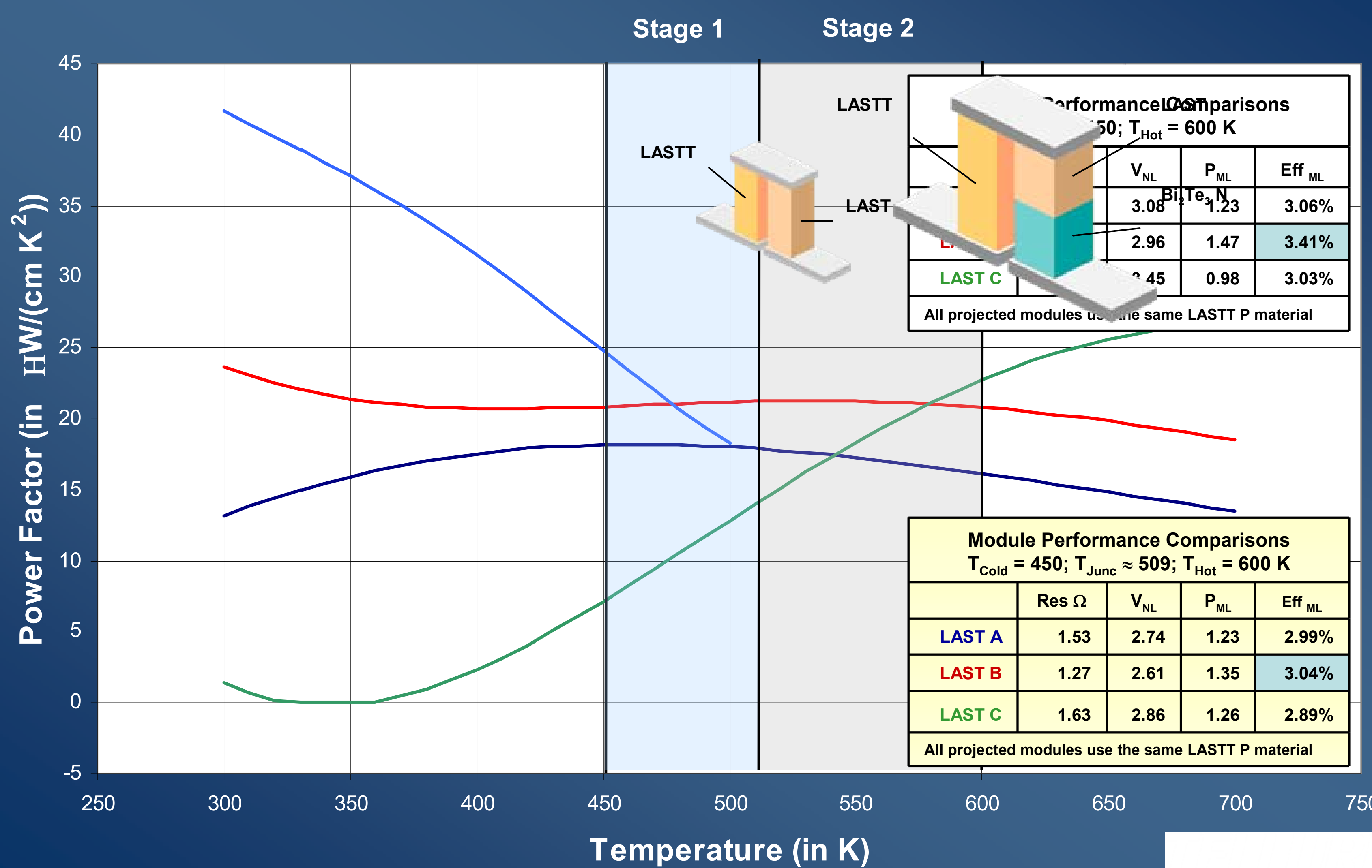
Module Performance Comparisons
T_{Cold} = 350; $T_{Junc} \approx$ 422; T_{Hot} = 500 K

	Res Ω	V_{NL}	P_{ML}	Eff $_{ML}$
LAST A	1.25	3.96	3.13	6.05%
LAST B	1.12	3.93	3.43	6.18%
LAST C	3.17	4.27	1.44	3.28%

All projected modules use the same LASTT P material

Module Performance

Power Factor of Four Materials



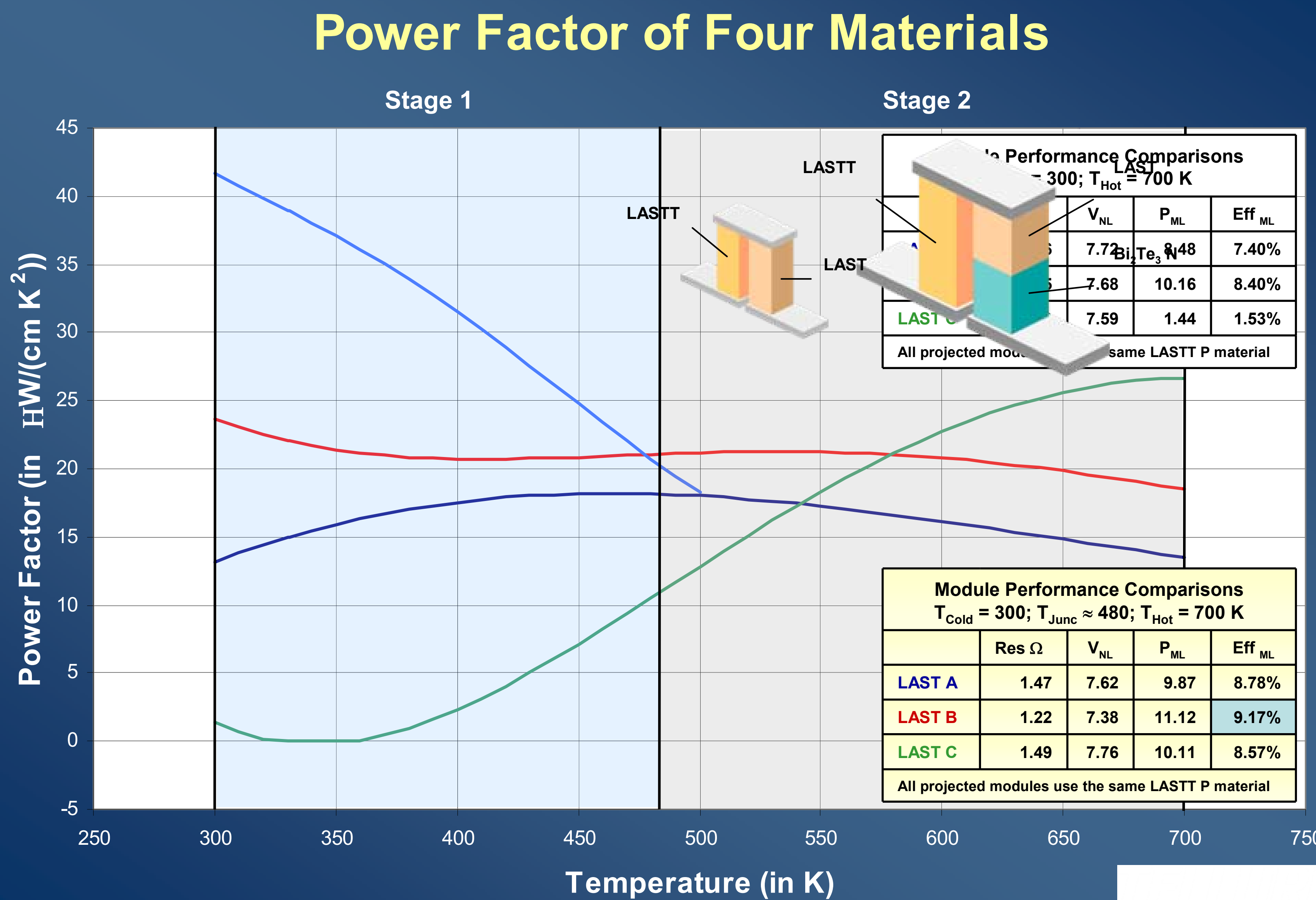
...erformance Comparisons ...50; T_{Hot} = 600 K				
	[illegible]	V_{NL}	P_{ML}	Eff_{ML}
[illegible]	[illegible]	3.08	1.23	3.06%
LA...	[illegible]	2.96	1.47	3.41%
LAST C	[illegible]	?.45	0.98	3.03%
All projected modules us... ...e same LASTT P material				

Module Performance Comparisons
T_{Cold} = 450; $T_{Junc} \approx$ 509; T_{Hot} = 600 K

	Res Ω	V_{NL}	P_{ML}	Eff_{ML}
LAST A	1.53	2.74	1.23	2.99%
LAST B	1.27	2.61	1.35	3.04%
LAST C	1.63	2.86	1.26	2.89%

All projected modules use the same LASTT P material

Module Performance



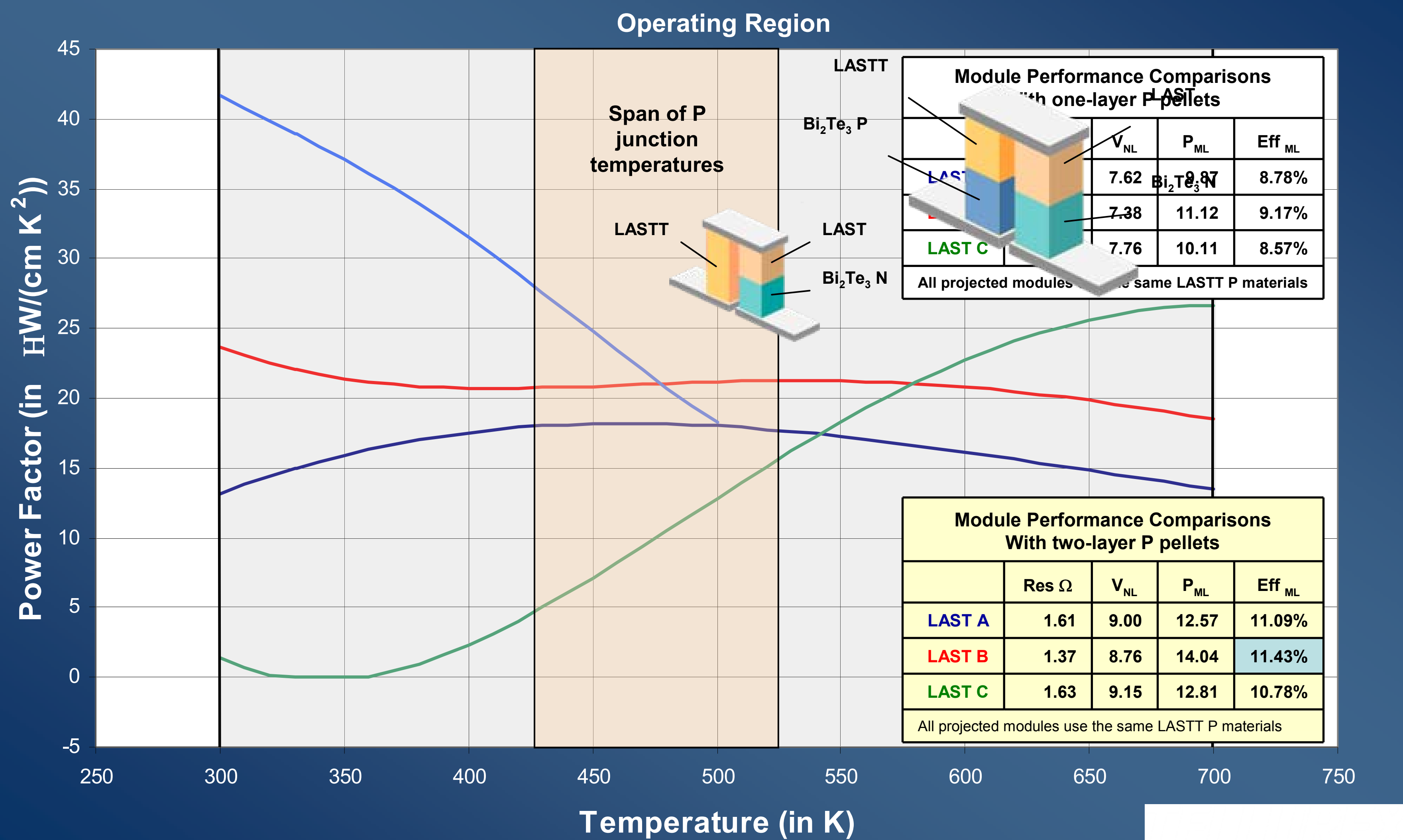
Module Performance Comparisons
T_{Cold} = 300; $T_{Junc} \approx$ 480; T_{Hot} = 700 K

	Res Ω	V_{NL}	P_{ML}	Eff_{ML}
LAST A	1.47	7.62	9.87	8.78%
LAST B	1.22	7.38	11.12	9.17%
LAST C	1.49	7.76	10.11	8.57%

All projected modules use the same LASTT P material

Module Performance

Power Factor of Four Materials



Module Performance Comparisons With one-layer P pellets

	Res Ω	V_{NL}	P_{ML}	Eff_{ML}
[illegible]	[illegible]	7.62	9.87	8.78%
[illegible]	[illegible]	7.38	11.12	9.17%
LAST C	[illegible]	7.76	10.11	8.57%

All projected modules [illegible] same LASTT P materials

Module Performance Comparisons With two-layer P pellets

	Res Ω	V_{NL}	P_{ML}	Eff_{ML}
LAST A	1.61	9.00	12.57	11.09%
LAST B	1.37	8.76	14.04	11.43%
LAST C	1.63	9.15	12.81	10.78%

All projected modules use the same LASTT P materials

Research Collaborators

Acknowledgements

These institutions and agencies have been vital collaborators.

MICHIGAN STATE UNIVERSITY

Pacific Northwest NATIONAL LABORATORY

NORTHWESTERN UNIVERSITY

MichiganTech

OFFICE OF NAVAL RESEARCH S&T ONR Revolutionary Research . . . Relevant Results

UNIVERSITY OF MICHIGAN

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Conclusions

- Heat harvesting and intentional thermoelectric power generation applications come in various temperature regimes and ΔT's
- Thermoelectric materials that can be customized for an application would be beneficial in optimizing a system's performance (conv. eff.,voltage, power)
- From a production standpoint, if one material can be tuned for optimum use at varied temperatures, this would have commercial and engineering benefits (lower cost , same equipment, very similar CTE's)
- LAST materials have been shown to have a degree of tunability by using powder metallurgy processes
- Combined with bismuth telluride, overall performance of a LAST(T) based system indicates conversion efficiencies of over 10%

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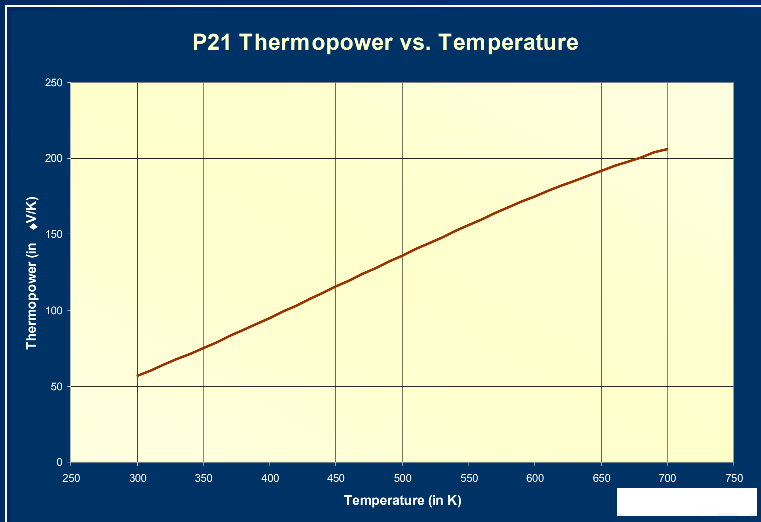
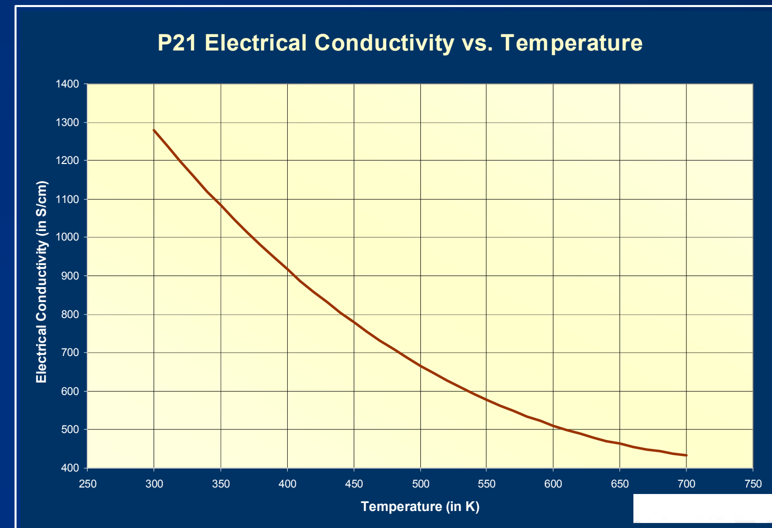
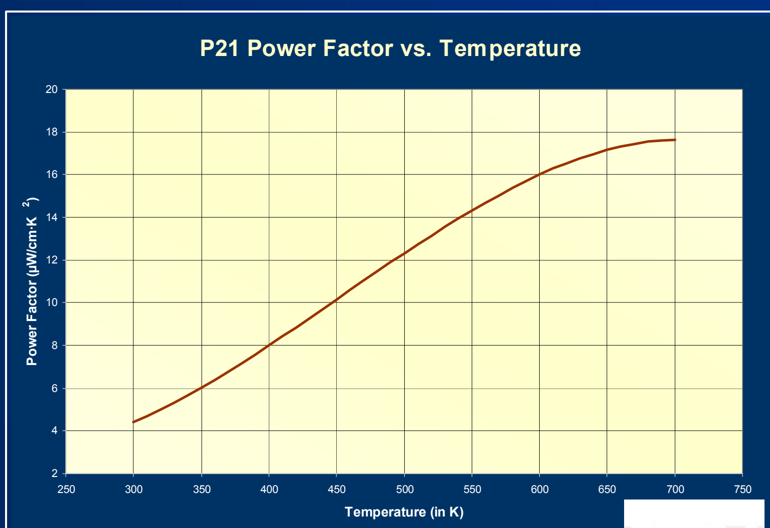
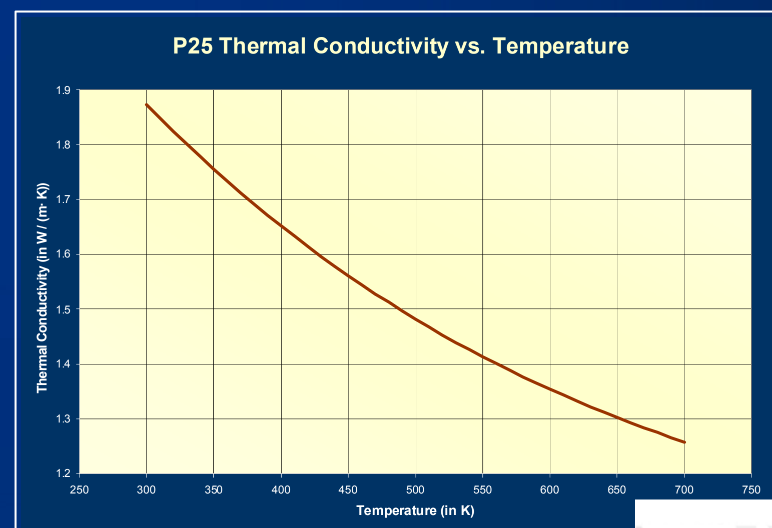
Reference on LASTT









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