

VAST[®] Grid Edge Technologies

Enabling Renewable Power

VAST[®] TriFluid[™] Combustor

VAST[®] FastRamp[™] Turbine

VAST[®] Power Cycle

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How Do We Keep The Lights On?

VAST's Disruptive Solution

Challenges

- Preventing Renewable Grid Collapse & Blackouts
- Reducing Greenhouse Gases & other Emissions
- Reducing the Costs of Current Technologies



CALIFORNIA BLACKOUT

Solution

- VAST Ultra-clean FastRamp™ Turbine Provides:
 - Profitable Rapid Backup Power
 - Higher Internal Rate of Return (IRR)
- VAST TriFluid Combustor
 - 20% - 24% Higher Efficiency with Lower CO₂
 - Lowest NOx & CO - Without Catalysts



So. AUSTRALIA STATE BLACKOUT

The Market

- Driven by Rapid Mandated Growth of Renewable Power
 - Storage is Expensive with Limited Duration
- Driven by Rapid Emerging Market Growth Globally

VAST's Disruptive Solutions

1. Ultra-low NOx and CO Emissions

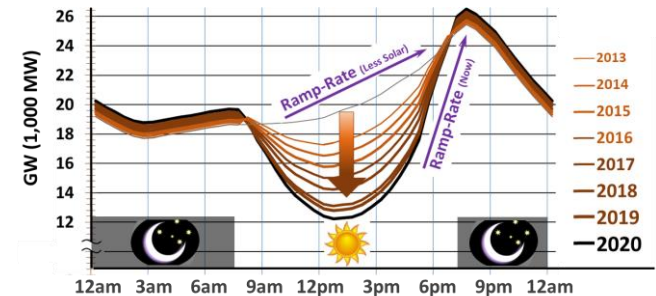
- Expect Best Available Control Technology (BACT)
- Much Lower than All Emissions Requirements without Catalysts

2. Best in Class Economic Performance

- Higher IRR than Combined Cycle & Peakers as Renewables Increase
- VAST Outperforms Peakers & Combined Cycle (1:1) Turbines when Utilization Drops Below 70% Full Capacity
- Higher Net Power & Efficiency with Lower Emissions at Part Load

3. Ground-breaking FastRamp™ Turbine

- Designed for sub-10 minute Dispatch Ramp Rate
- “Spinning Reserve” with Lower Emissions
- Reduces Turbine Thermal Cycle Fatigue and Costly Maintenance



4. Multi-fuel Capability - Natural Gas, Biogas, Hydrogen, Ammonia, Diesel, Methanol, Biofuels, etc.

VAST's Breakthrough Technologies

Clean Air Mandates Require ~95% Lower Gas Turbine Emissions

VAST Power Technologies:

- Eliminate SCR* Catalysts - 5% of Gas Turbine Capital Cost
- Eliminate SCR Ammonia Operating Cost and Risks
- Lower Emissions from Rapid Start-up & Pilot Flames
- Eliminate Startup Emissions Plumes



Designing for Hydrogen & Ammonia with Below Mandated NOx Levels

Proprietary Design Refined via Department of Energy Grant

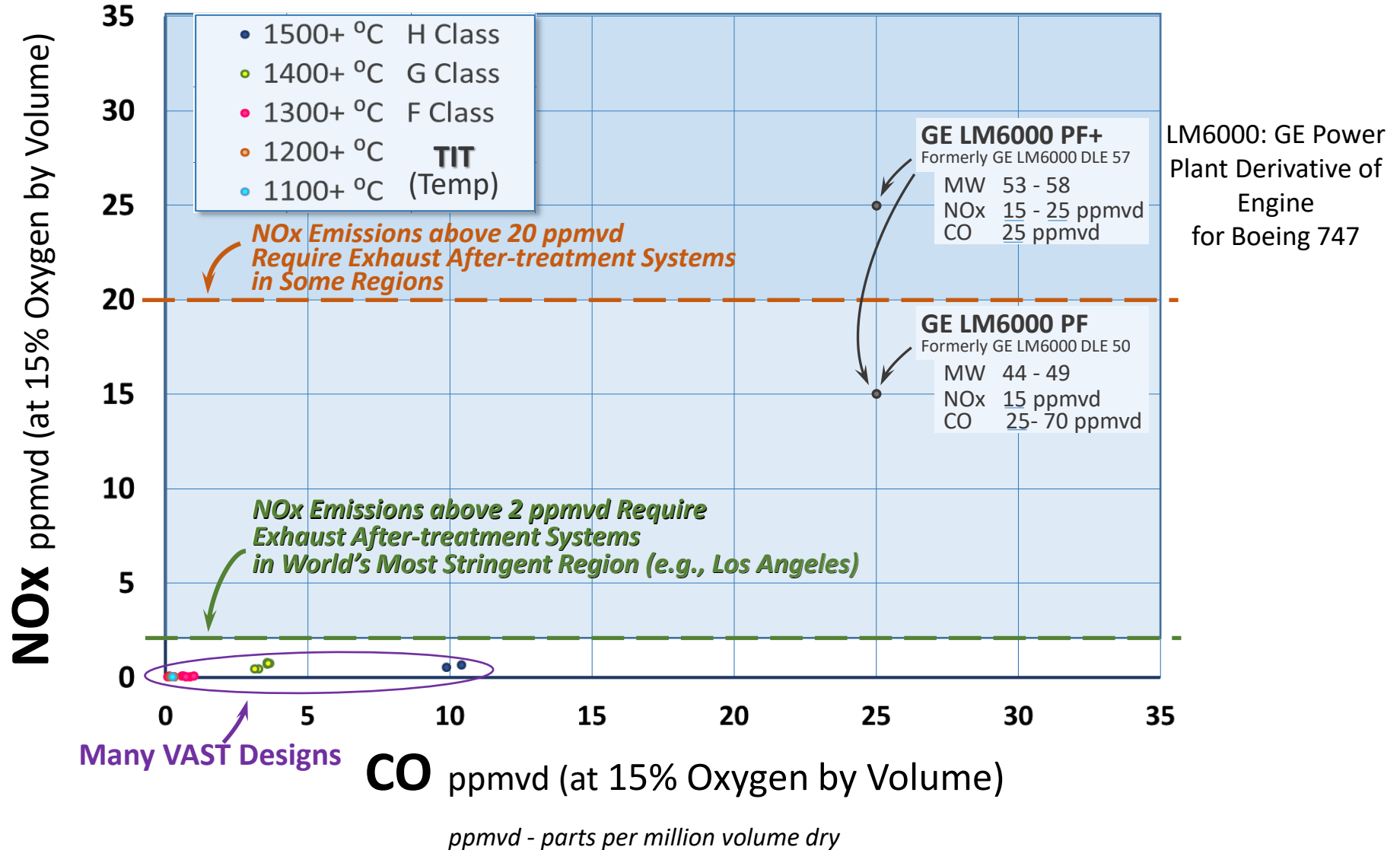
- VAST Designed Combustor with > 100 Model Parameters
 - Manufactured via 3D Printing /Additive Manufacturing
- Argonne National Lab Supercomputer Modeled VAST Combustion
 - 16,000,000 Core Hours of Computational Fluid Dynamics (CFD)
- Lawrence Livermore Lab Modeled Major Design Configurations
 - Optimized Parameters via Neural Networks & Deep Machine Learning

**SCR - Selective Catalytic Reduction*

Achieving Lowest NOx and CO

Emissions at Combustor Outlet / Turbine Inlet

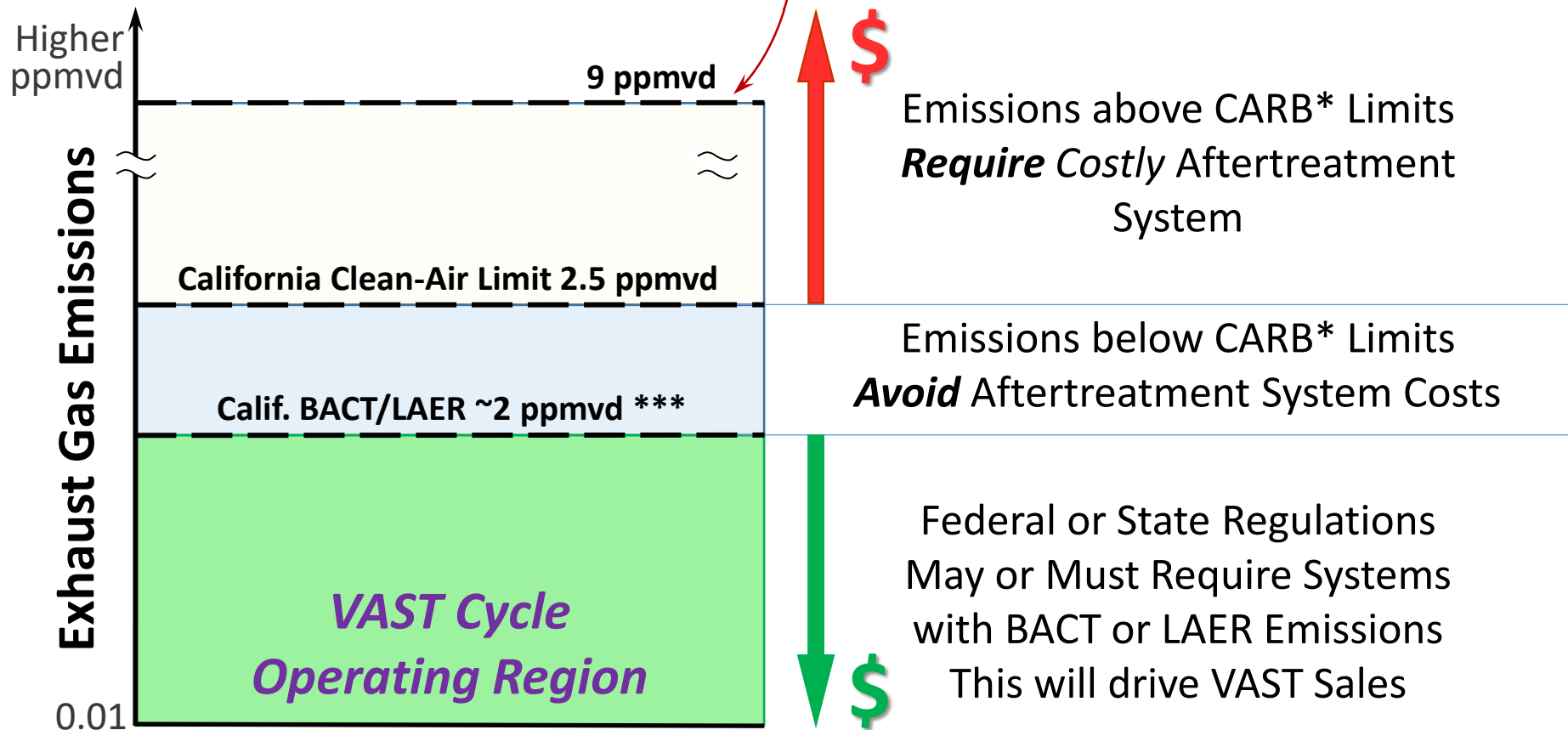
NOx -vs- CO



Source: ge.com/content/dam/gepower/global/en_US/documents/gas/gas-turbines/aero-products-specs/lm6000-fact-sheet-product-specifications.pdf

California Clean Air Requirements

Typical Peaker Gas Turbine at 9 - 25 ppmvd NOx
Without Exhaust Gas Aftertreatment



* CARB - California Air Resources Board

** BACT - Best Available Control Technology

*** CARB BACT ~2 ppmvd NOx at 15% O₂ using Exhaust Catalyst & Ammonia

LAER - Federal Standard: Lowest Achievable Emission Rate

ppmvd - parts per million volume dry

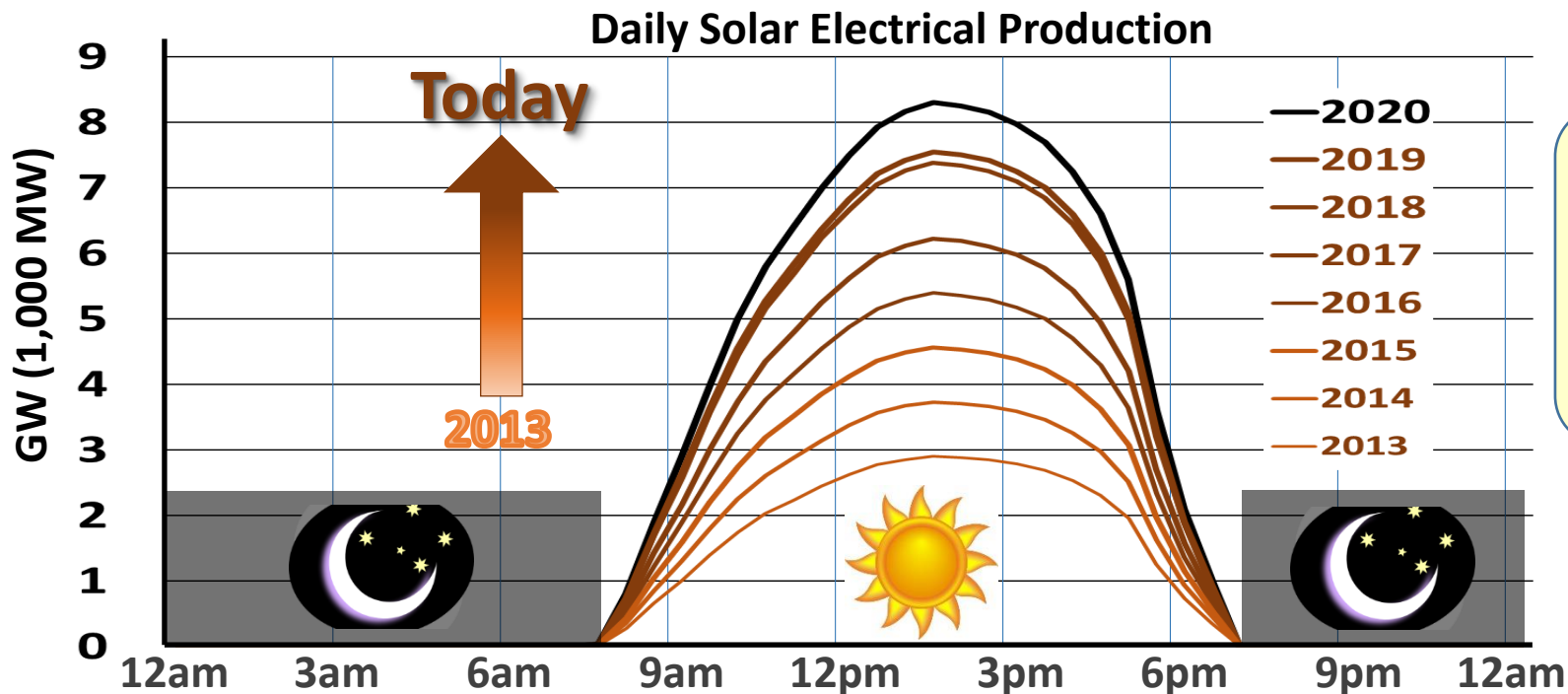
Renewable Energy Mandates

Solar and Wind Deployment is Skyrocketing

Major Solar Power Production during Daylight Hours

Each year, additional Solar is installed Resulting in Greater Day-time Energy Production Annually

Massive Change - California Mandated 100% Carbon Neutral by 2045



Solar Power Production Is Increasing Significantly Annually

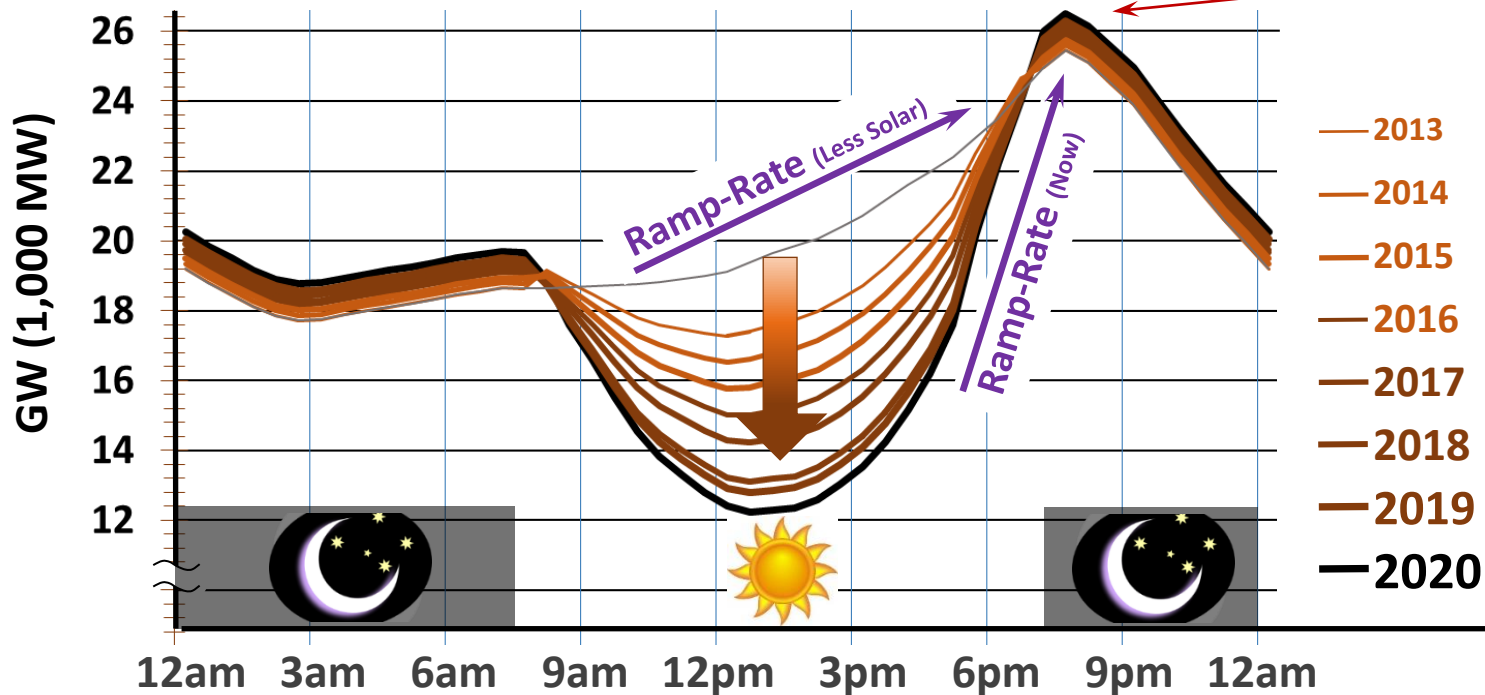
Source: CAISO - Typical Spring Day

Looming Crisis Supporting Renewable Energy

Mid-day Solar Displaces Conventional Power during Sunniest Hours
 Evening Peak Demand still Grows - even with Solar Generation
 Annually Increasing Solar Creates Steeper Power Ramp-Rate
 Power Providers must Precisely match Demand at Every Moment
 Full Power Backup of Solar & Wind is essential to Prevent Blackouts
 Intermittent Renewables increase Conventional Turbine Thermal Cycle
 Fatigue / Damage and Costly Maintenance



VAST® FastRamp™ Turbines enable >50% Renewable Power Grids

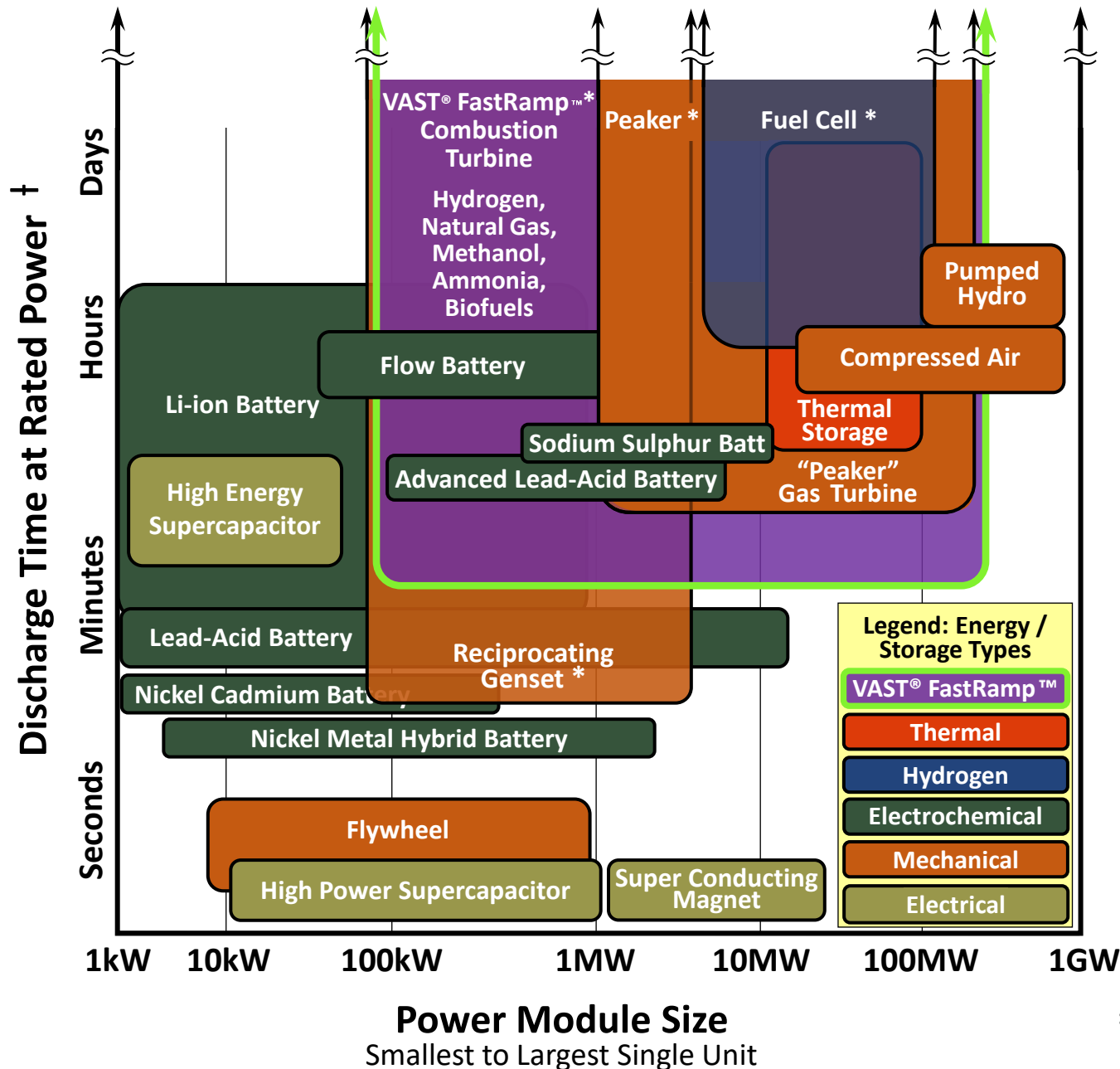


“Duck Curve”
 Gets Steeper
 Each Year
 Rapidly Rising
 Risk of
 Grid
 Collapse



Source: CAISO - Typical Spring Day

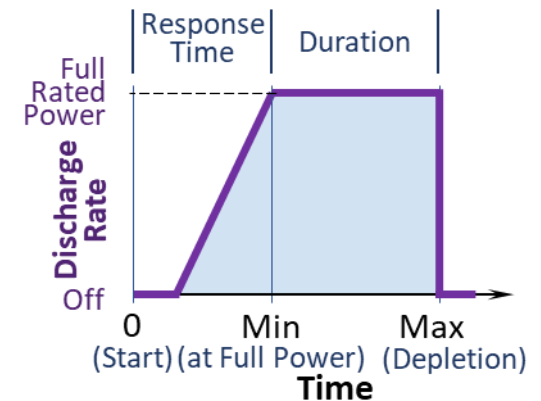
Electrical Grid Stabilization Technologies



* **VAST® FastRamp™**
Combusts a wide range of fuels with ultra-low emissions. Discharge Duration is limited only by fuel supply.

* **Fuel Cell, Reciprocating Genset, "Peaker" Gas Turbine**
Discharge Duration is limited only by fuel supply.

† **Discharge Time at Rated Power**
Response Time (minimum) & Duration (maximum)



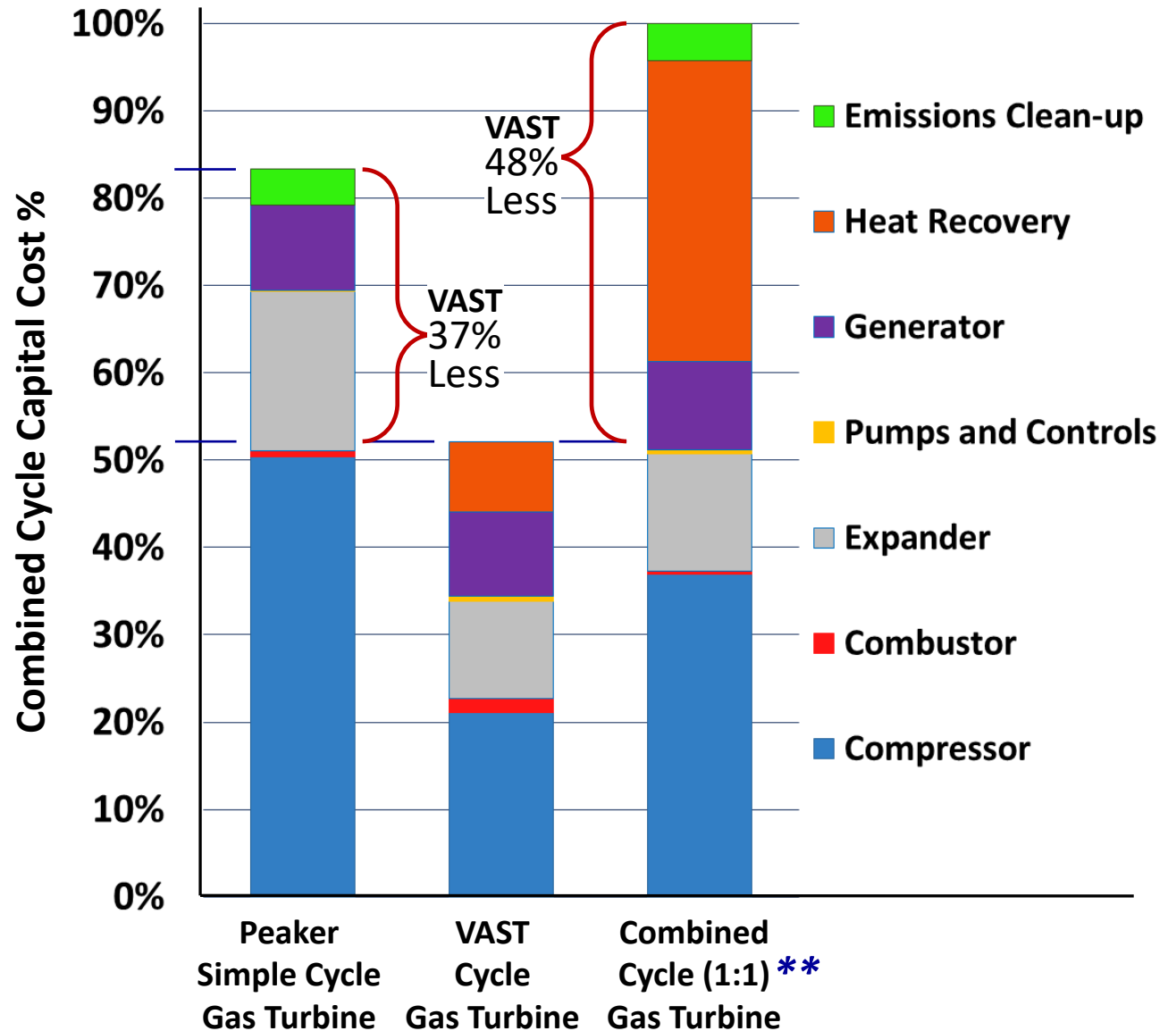
‡ Batteries & Supercapacitors have Sub-second Response Time

Capital Cost Comparison

VAST Generates Same Power Output with Significantly Lower CapEx *
 -vs- Peaker Simple Cycle and Combined Cycle Gas Turbines

All 3 Turbines Generate 50 MW

* Gas Turbine Purchase Cost without Installation



**1 Gas Turbine with 1 Steam Expander

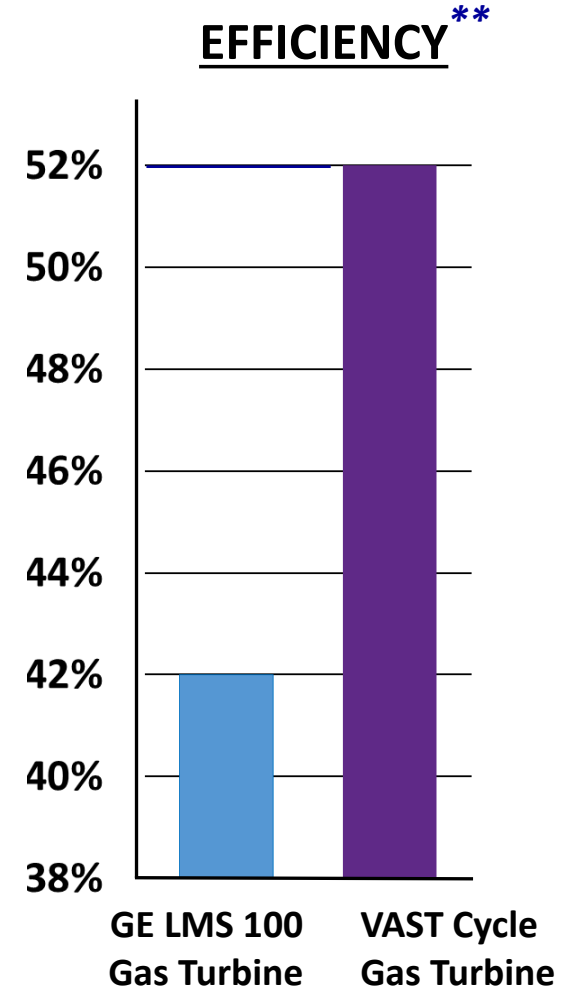
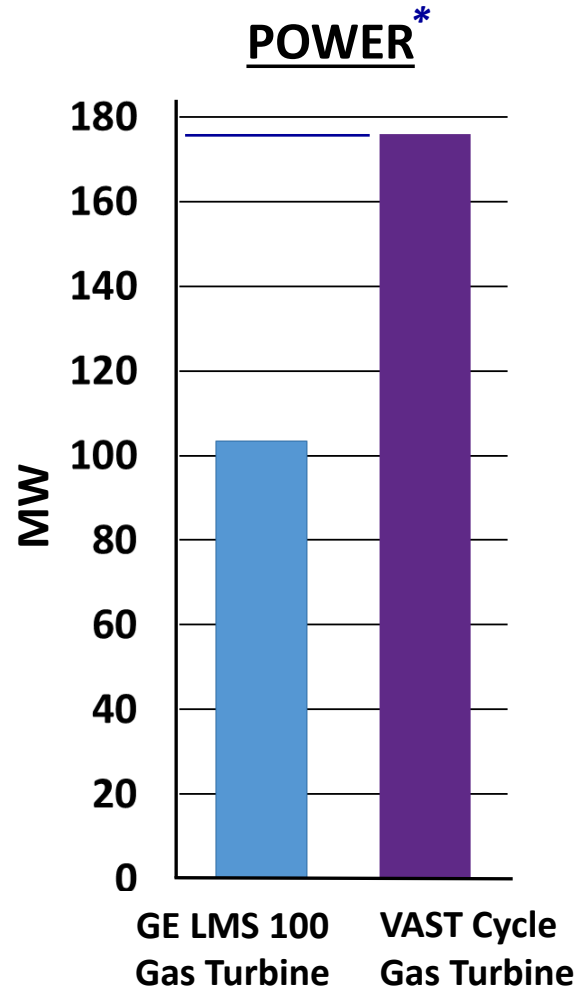
Performance Comparison

VAST Generates
Up to 70% More Power
and
24% Better Efficiency

-vs-

GE LMS 100
100 MW
Gas Turbine

With the
Same Expander Area
Same Pressure



** VAST Produces ~70% More Electricity
with same expander, depending on Pressure*

*** VAST has 24% Higher Efficiency
Consuming 19% Less Fuel
Reducing CO₂ by ~19%*

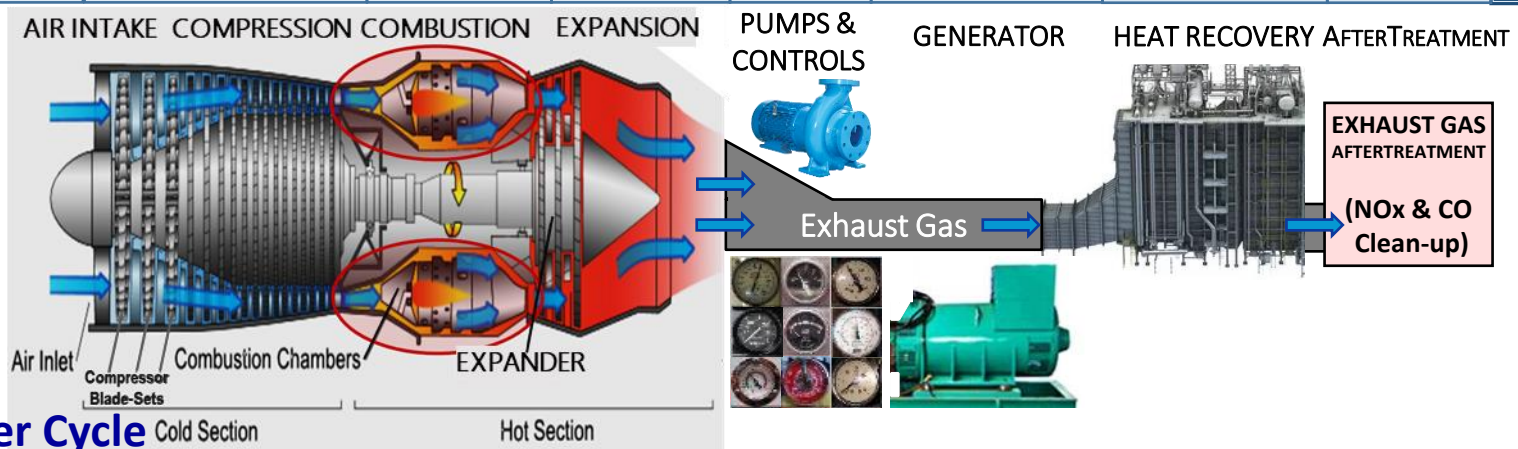
Capital Cost Comparison

50 MW Gas Turbines

VAST Generates
the Same Power
using 37% Less CapEx

Conventional Simple Cycle - Peaker

% of Capital Cost	60%	0.8%	22%	0.2%	12%	0%	5%	100%
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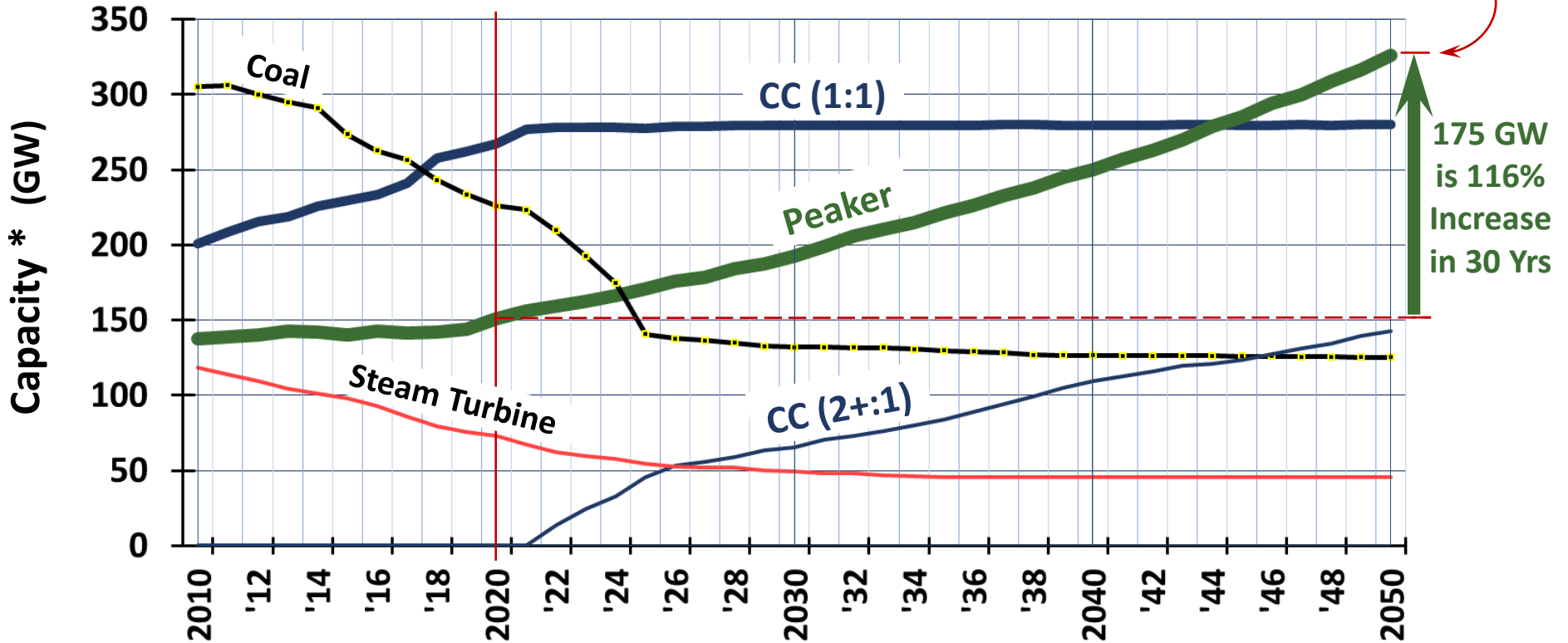
VAST Power Cycle

% of Conventional Capital Cost	25%	2%	13.4%	0.6%	12%	9.6%	0%	62.6%
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CapEx - Capital Expense: Money to Purchase Working System - Upfront Cost - without Installation

U.S. Fossil Fuel Electric Power - Installed Capacity*

Peaker Growth Essential to Prevent Blackouts due to Renewables Growth



2010	2020	2030	2040	2050
201	267	280	280	280
138	151	193	250	326
305	226	132	127	125
0	0	66	109	143
118	73	49	45	45

* Name Plate
Rating
Installed Power

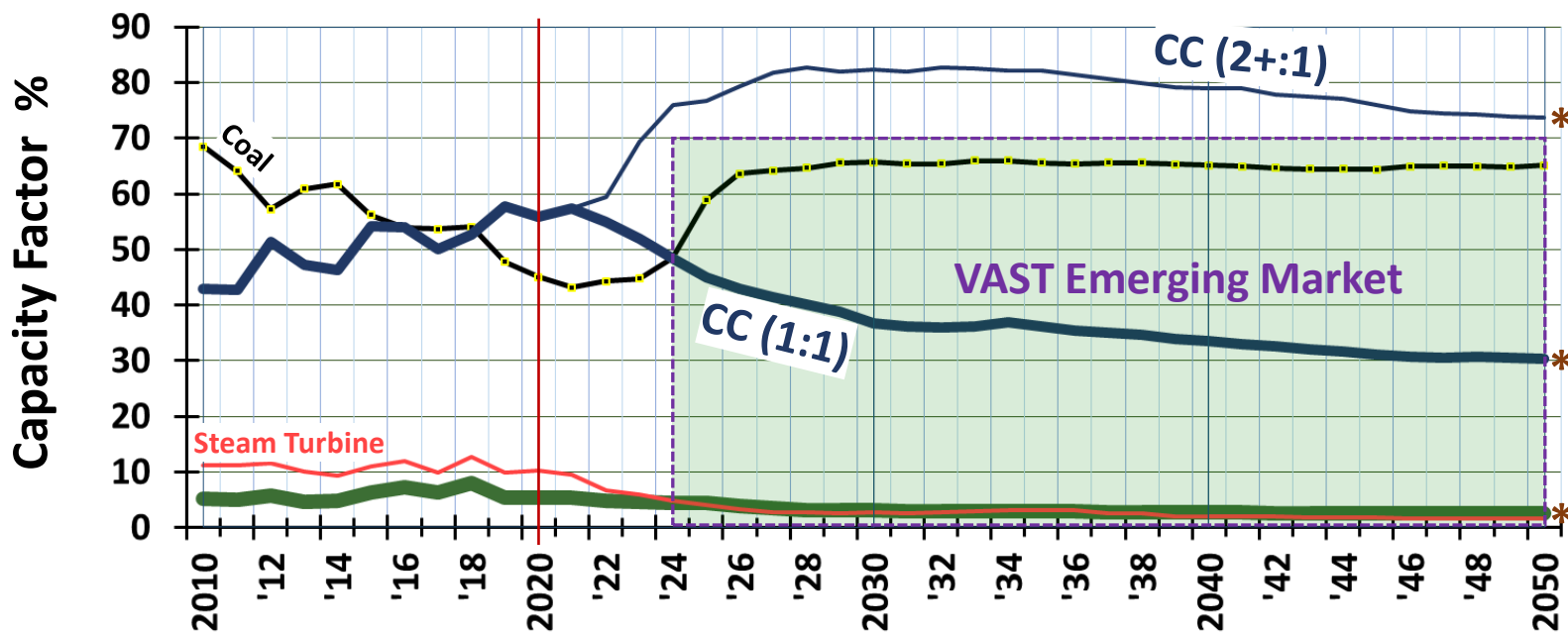
- Combined Cycle (1:1)** Gas:Steam Turbine
- Peaker Gas Turbine
- Coal
- Combined Cycle (2+:1) Gas:Steam Turbine
- Oil or Gas Steam Turbine

Source: U.S. Energy Information Administration - EIA.Gov

**1 Gas Turbine with
1 Steam Expander

U.S. Fossil Fuel Electric Power - Capacity Factor

VAST Creates New Intermediate Load Market



2010	2020	2030	2040	2050
	56%	82%	79%	74%
68%	45%	66%	65%	65%
43%	56%	37%	34%	30%
5%	5%	3%	3%	3%
11%	10%	3%	2%	2%

- Combined Cycle (2+:1) Gas:Steam Turbine
- Coal
- Combined Cycle (1:1)** Gas:Steam Turbine
- Peaker Gas Turbine
- Oil or Gas Steam Turbine

Capacity Factor = Actual Operating Hrs / Total Annual Hrs

* Base Load Declines Driven by Mandated Renewables Growth

Source: U.S. Energy Information Administration - EIA.Gov

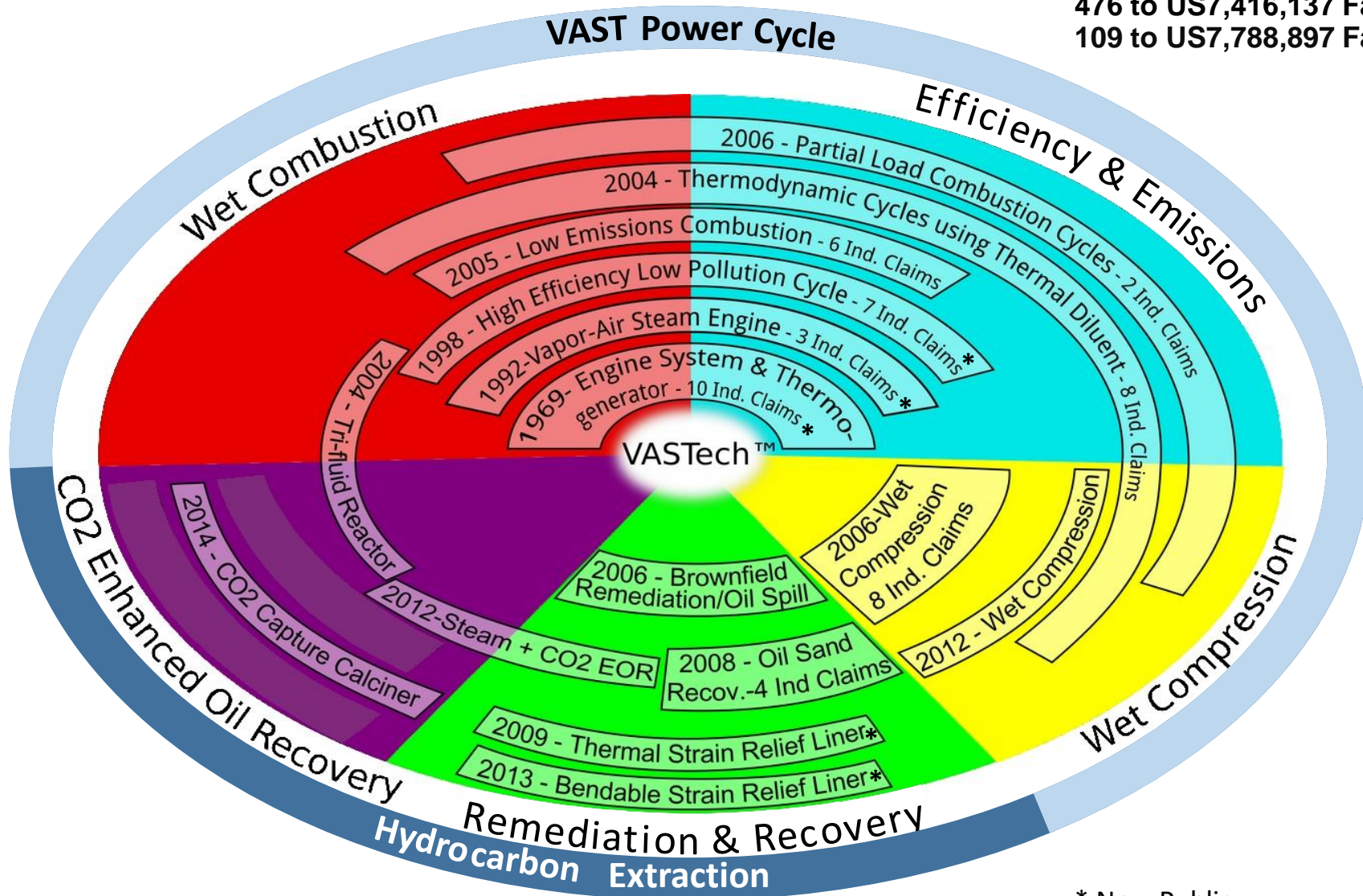
****1 Gas Turbine with
1 Steam Expander**

VAST Patent Portfolio - 34 Patents Worldwide

17 US Allowed Patents since 2004, others in preparation

1,829 USPTO Citations to VAST Patents & Applications

Highly Cited
 122 to US6,289,666 Family
 476 to US7,523,603 Family
 476 to US7,416,137 Family
 109 to US7,788,897 Family



* Now Public

DOE Backs VAST with Expertise of 2 National Labs

Phase 1 High Performance Computing for Manufacturing (HPC4Mfg) Grant hpc4mfg.llnl.gov

- \$300K DOE Award to support VAST's Combustor Optimization for 12 months
- Utilized 1 Million Core Hours of Supercomputer Run-time
- \$102K VAST Contribution In-kind*

Phase 2 High Performance Computing for Manufacturing (HPC4Mfg) Grant hpc4mfg.llnl.gov

- \$300K DOE Award to support Combustor Optimization for 12 months
- Allocates 15 Million Core Hours of Supercomputer Run-time
- \$150K VAST Contribution In-kind + \$75K Cash

Argonne National Laboratory (ANL), Illinois

www.anl.gov

- Multidisciplinary Science and Engineering Research Center with US Dept. of Energy
- Runs CFD (Computational Fluid Dynamics) Modeling of VAST Combustor variations
- Performs Detailed Physics-based, Combustion and Fluid (Fuel, Air, Water, Steam) Flow Simulations for VAST Combustor Design Trade-offs

Lawrence Livermore National Laboratory (LLNL), California

www.llnl.gov

- Multi-disciplinary RD&D Center on Weapons and Fusion Energy
- Develops System-wide Optimization using Neural Network Modeling
- Calculated Reduced Order Equations with R^2 of 0.99+ which enables VAST to perform Future Advanced Modeling on Laptops, without requiring Supercomputers

**VAST provided an additional \$258K In-kind Labor and Cash*

VAST Technology Advisors

- **Dr. Albert (Al) Erisman**, Seattle, WA: 32 year career at Boeing, Director of Technology. Honored as inaugural Boeing Senior Technical Fellow. On Committees for: National Science Foundation, National Academy of Sciences, National Institute for Standards & Technology. On the Review Board of the Computing Division, Los Alamos National Labs. Al authored:
 - *Direct Methods for Sparse Matrices: Second Edition* Oxford University Press
 - *Electric Power Problems: The Mathematical Challenge*; Soc. Industrial & Applied Mathematics
- **Bill Job**, Nashville, TN: Entrepreneur - 30+ years in China & Hong Kong - built six businesses. Now remotely managing them and consulting in Middle East, Asia, Africa & US. Developing IT-based, aeroponic urban food production in China.
- **Gary Neidig**, Plymouth, IN: President ITAMCO. Deeply experienced in developing and commercializing precision manufactured industrial products by both subtractive and additive processes. ITAMCO is a leading innovator in Additive Manufacturing (AM). It recently completed the sale to Siemens of an ITAMCO AM Software spin-off.
- **Mark O'Halloran**, Chicago, IL: CFO & Director of Economic Development - Together Chicago. Serial entrepreneur & University of Chicago Graduate School of Business MBA.

VAST Team

- **Gary Ginter**, Chicago, IL: Chairman & Founder

Gary Ginter is a serial entrepreneur who helped develop multiple organizations. Two were sold for over \$750 million.

Gary helped lead Chicago Research and Trading Group, a world-class futures and options market-maker. After 17 years, “CRT was sold to NationsBank for \$225 million cash plus other considerations. CRT had 750 employees, \$250 million in capital and offices in cities around the world. It owned more than 150 memberships on 19 securities exchanges and traded approximately 75 options and futures contracts on interest rates, equity indexes, petroleum and foreign exchange, as well as other instruments. CRT Government Securities Ltd. was one of 38 primary dealers that reported to and traded U.S. government securities directly with the Federal Reserve.” *Baltimore Sun Times*

Ginter served as the first Managing Director of Globex. It was the first futures and options electronic exchange founded by the CME Group with the Chicago Board of Trade and MATIF, the French futures exchange. Globex totally disrupted the futures industry. Today, over 90% of all trades worldwide in futures and futures options are done through Globex.

Ginter was a partner at Hull Trading Group, Chicago which was sold to Goldman Sachs for \$531 million. Ginter was offered a partnership in Goldman Sachs in that transaction. He declined to devote full-time to VAST.

VAST Team

- **Dr. David Hagen**, Goshen, IN: Chief Scientist & Co-founder

David is VAST's lead inventor with 17 (of his 23) US patents systematically covering an array of VAST applications. He is a world expert in gas turbine Wet Combustion. US patent examiners frequently cite his wet cycle patents.

With Engineering Design and Physical Chemistry degrees, David brings wide interdisciplinary skills. He co-chaired an ASME's Power Gen Conference seminar on Alternative Gas Turbine Cycles. He co-designed a mobile alluvial mining system. He chaired the 13 nation coconut food standards committee. His published coconut energy systems reviews and analysis were well received. David wrote a 330 page technology review on solar power technologies to reduce greenhouse emissions for the Australian government.

- **John O'Halloran**, Columbus, IN: President & Chief Technology Officer

John was CTO at Cummins - leader in engines, power generators, and filtration products. He launched and led Cummins Research and Technology India (CRTI), an internationally recognized hub for high-end engineering innovation. CRTI provides product design and optimization for Cummins engineering centers worldwide. Through CRTI, John achieved annual savings for Cummins of over \$10 million/year.

John was CTO of the Indian wind turbine multi-national, Suzlon, where he managed 9 research and development centers in 5 countries with 950 engineers - increasing product profitability and market penetration, while reducing time-to-market.

Further Discussion?

Gary Ginter, Chairman & Founder

Gary.Ginter@VASTEnergySolutions.com

Dr. David Hagen, Chief Scientist & Co-founder

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John O'Halloran, President & Chief Technology Officer

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