

# Grid Edge Technologies

Incorporating

**VAST® TriFluid™ Combustor**

**VAST® FastRamp™ Turbine**

**VAST® Power Cycle**

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# How Do We Keep The Lights On?

## VAST's Disruptive Solution

### The Problem

- Prevent Renewable Grid Collapse & Blackouts
- Without Increasing Greenhouse Gases & other Emissions
- Current Technologies are Expensive



CALIFORNIA BLACKOUT

### The Solution

- VAST Ultra-clean FastRamp™ Turbine Provides:
  - Profitable Rapid Backup Power
  - Highest Internal Rate of Return (IRR)
- VAST TriFluid Combustor - Lowest Emissions without Catalysts - NOx & CO
  - 20% Lower CO<sub>2</sub> than Peakers



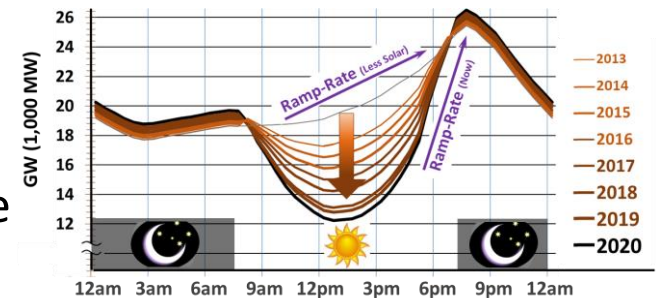
So. AUSTRALIA STATE BLACKOUT

### The Market

- Driven by Rapid Mandated Growth of Renewable Market
  - Backup Power + Storage must equal Total Renewable Supply
  - Storage is Expensive with Limited Duration
- Driven by Economics and Mandates

# VAST's Disruptive Solutions

1. Ultra-low NOx and CO Emissions
  - Expect Best Available Control Technology (BACT)
  - 20% lower CO<sub>2</sub> by Higher Efficiency
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 Efficiency & Lower Emissions at Part Load
3. Ground-breaking FastRamp™ Turbine
  - Designing 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, Hydrogen, Ammonia, Methanol, etc.



# VAST's Breakthrough Emission Technology

Clean Air Mandates Require ~95% Lower Gas Turbine Emissions

VAST Power Technologies:

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



Proprietary Design further Refined via Department of Energy Grant

VAST Designed Combustor with > 100 Model Parameters

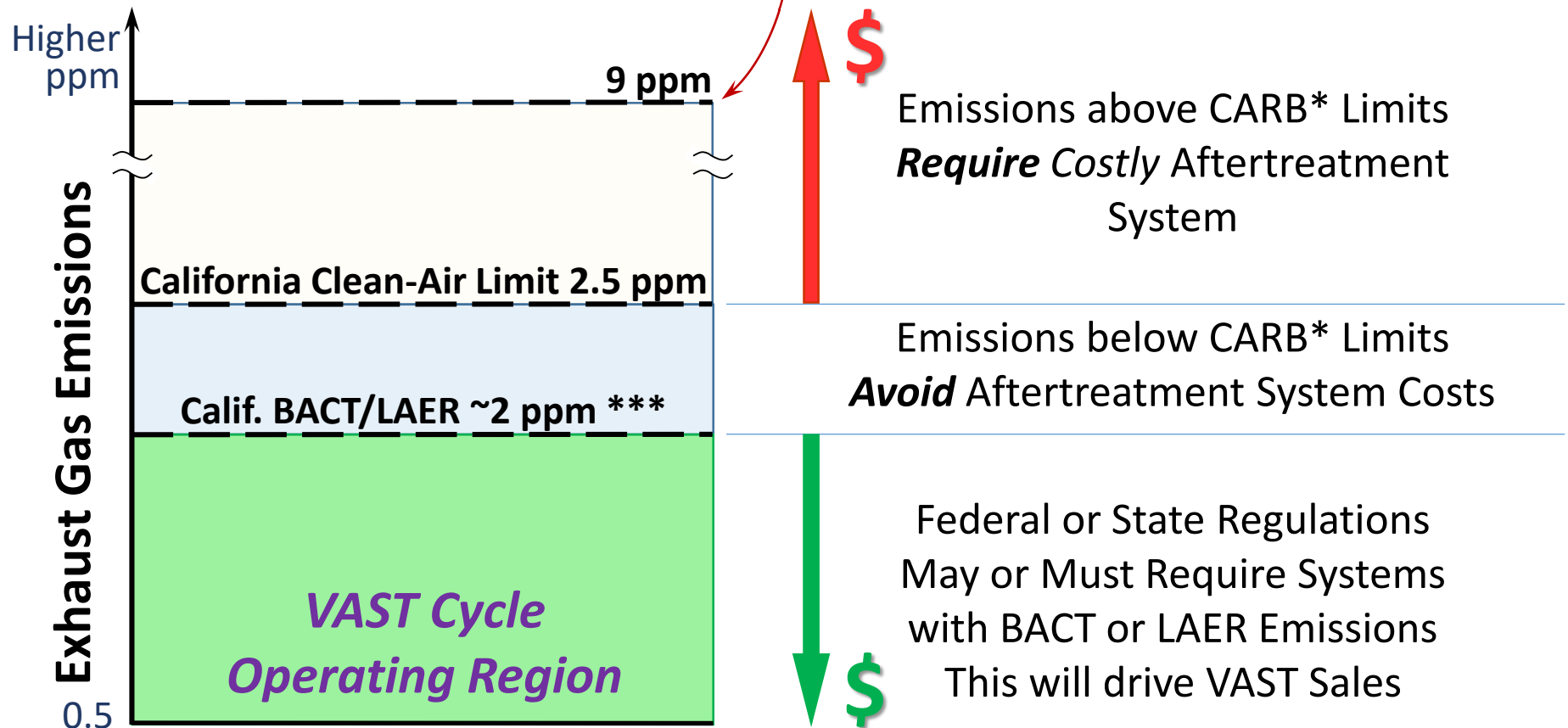
- Argonne National Lab Supercomputer Modeled VAST Emissions
  - 1,000,000 Core Hours of Computational Fluid Dynamics (CFD)
- Lawrence Livermore National Lab Supercomputer will Calculate Design Optimization Parameters via Neural Networks / Deep Machine Learning

Design for Low NOx with Hydrogen - Expect Best in Class

- Dept. of Energy Phase II includes Hydrogen and Ammonia Combustion

# California Clean Air Requirements

Typical Peaker Gas Turbine at 9 - 25 ppm NO<sub>x</sub>  
Without Exhaust Gas Aftertreatment



\* CARB - California Air Resources Board

\*\* BACT - Best Available Control Technology

\*\*\* CARB BACT ~2 ppm NO<sub>x</sub> at 15% O<sub>2</sub> using  
Exhaust Catalyst & Ammonia

LAER - Federal Standard: Lowest Achievable Emission Rate

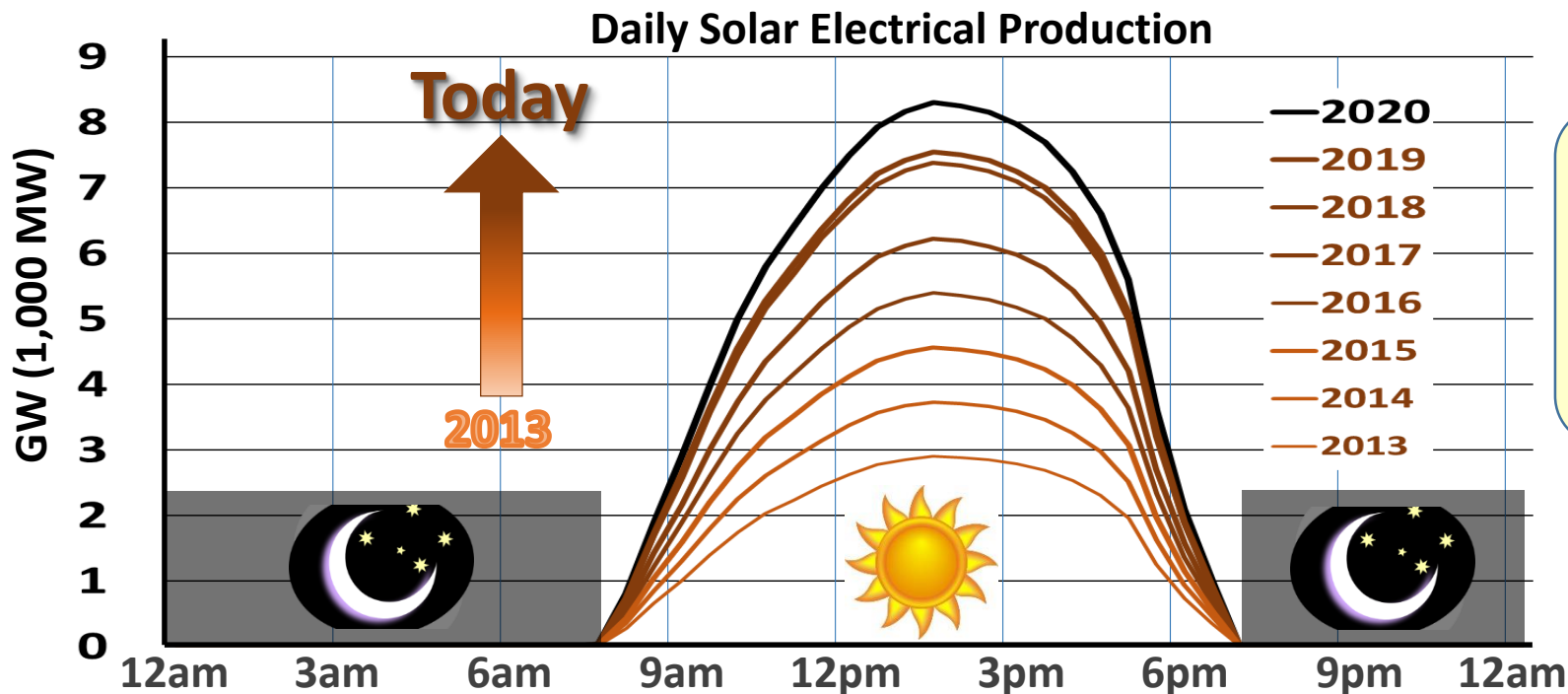
# Renewable Energy Mandates

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

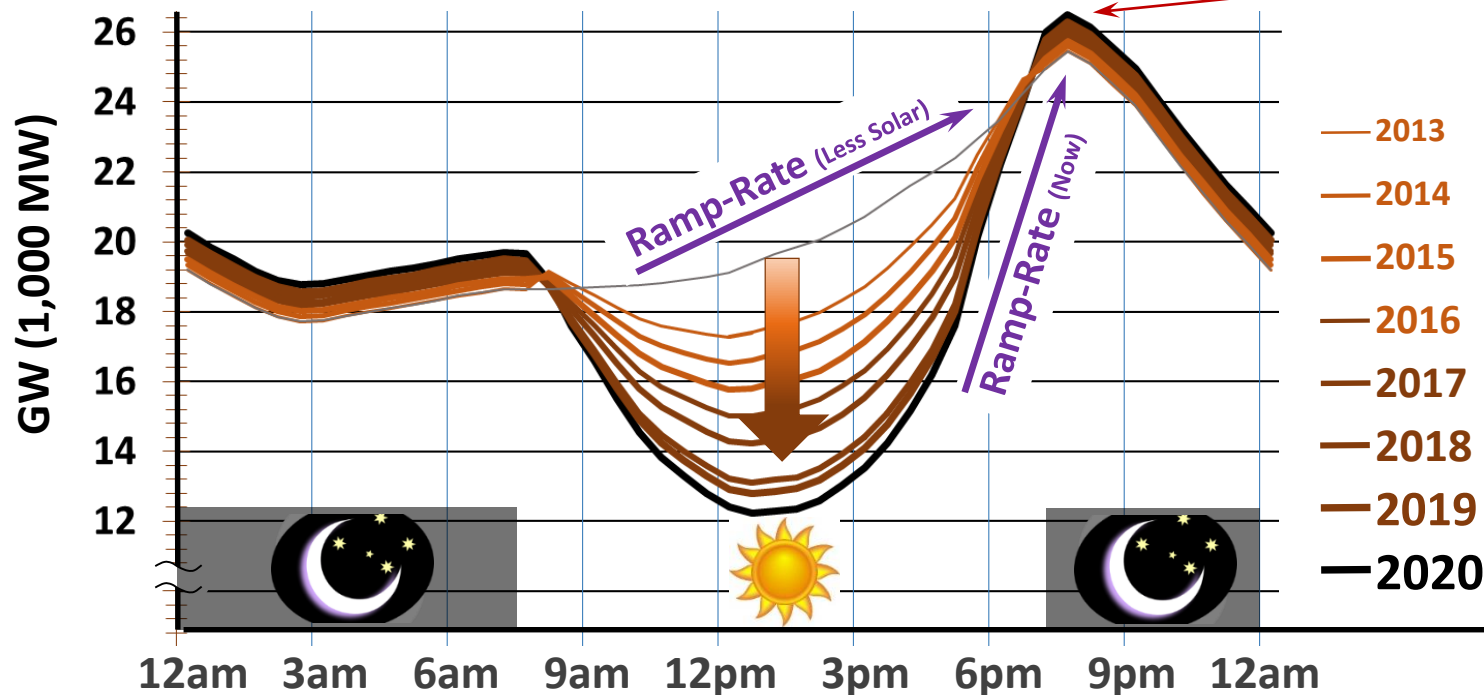


# Looming Crisis Supporting Renewable Energy

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 cause Conventional Turbine Thermal Cycle  
Fatigue / Damage and Costly Maintenance



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



“Duck Curve”  
Gets Steeper  
Each Year

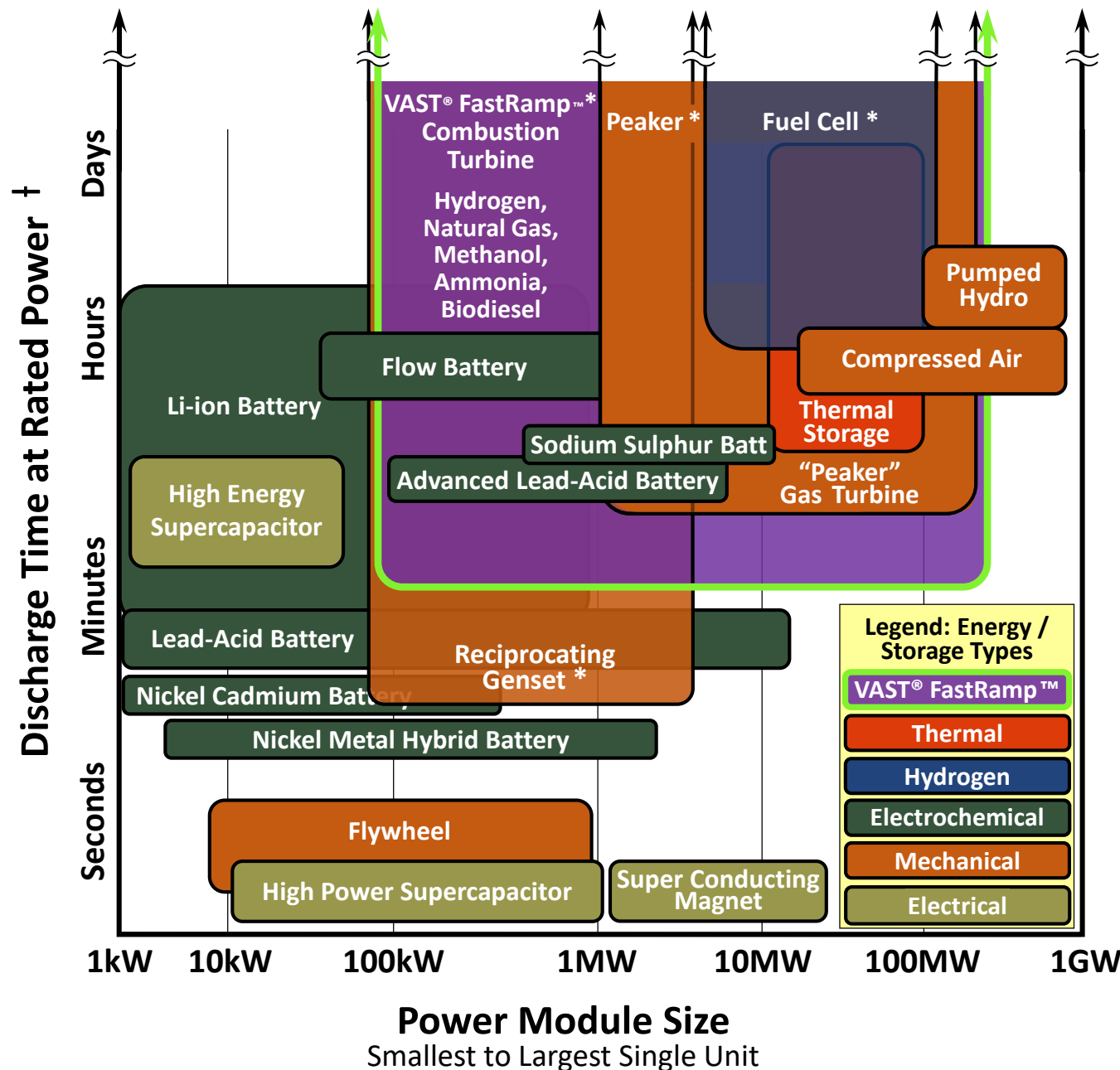
Rapidly Rising  
Risk of  
Grid  
Collapse



Source: CAISO - Typical Spring Day



# Electrical Grid Stabilization Technologies



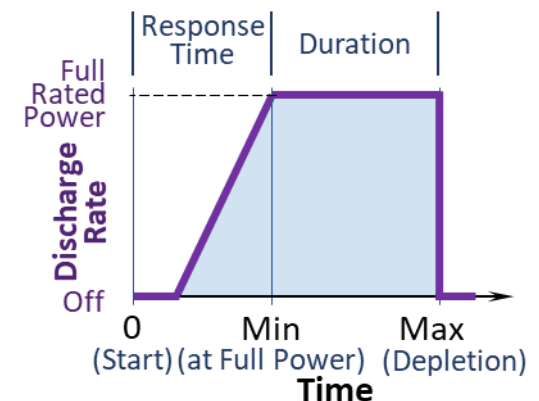
## \* VAST® FastRamp™

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)

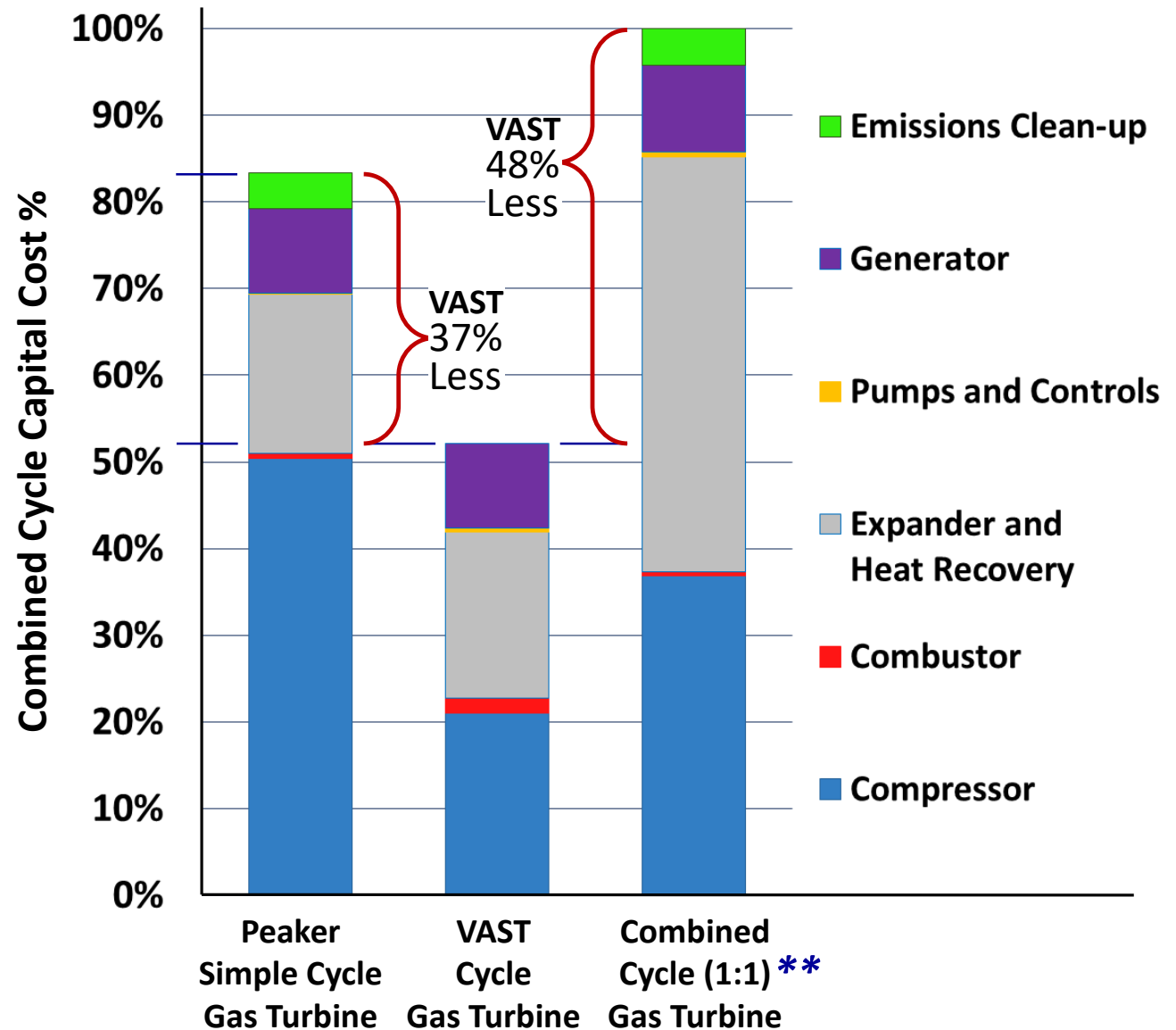


‡ Batteries & Supercapacitors have Sub-second Response Time

# Capital Cost Comparison

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

**\* 50 MW Generator  
Gas Turbine Purchase Cost without Installation**



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

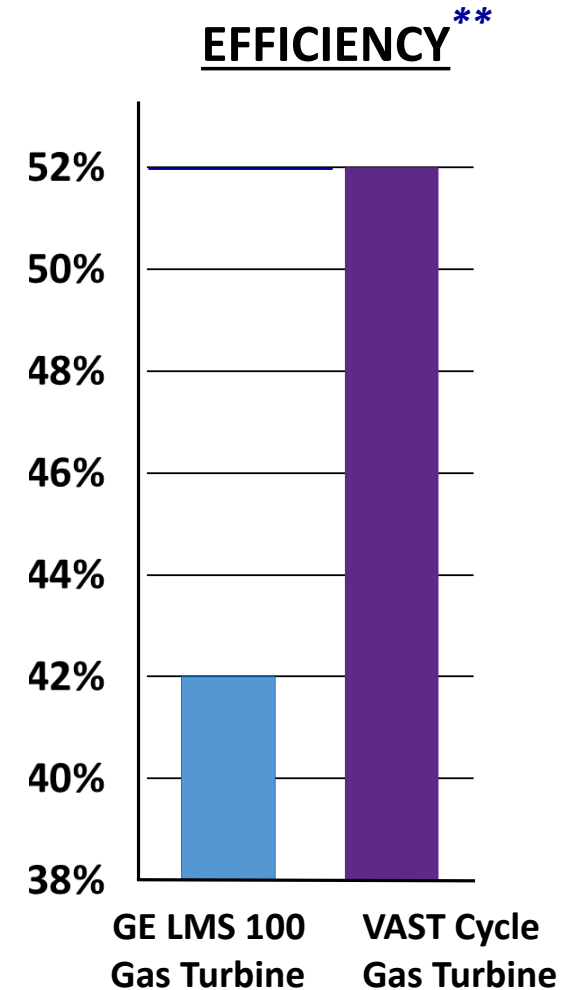
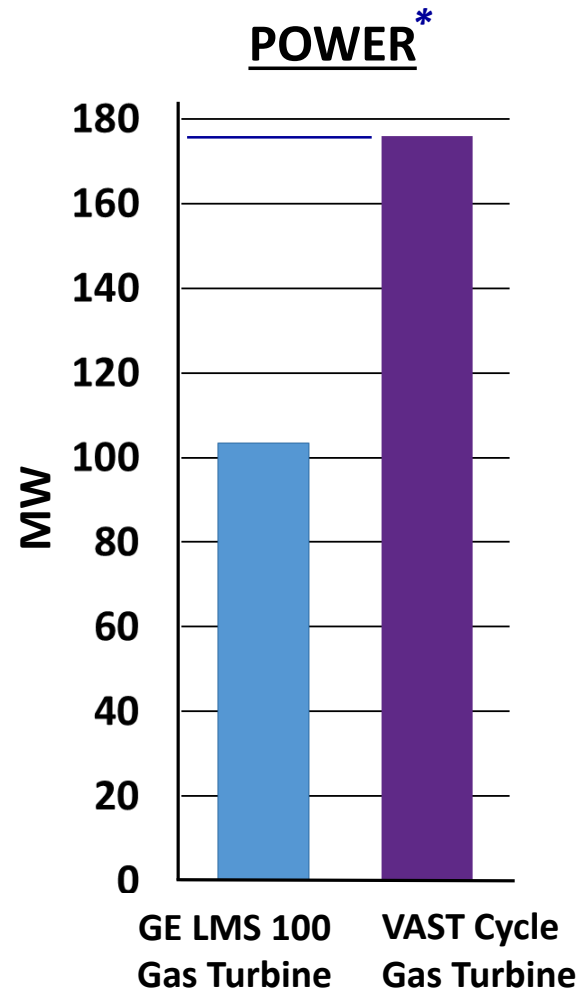
# Performance Comparison

**VAST Generates  
70% More Power  
with  
24% Better Efficiency**

**-vs-**

**GE LMS 100  
100 MW  
Gas Turbine**

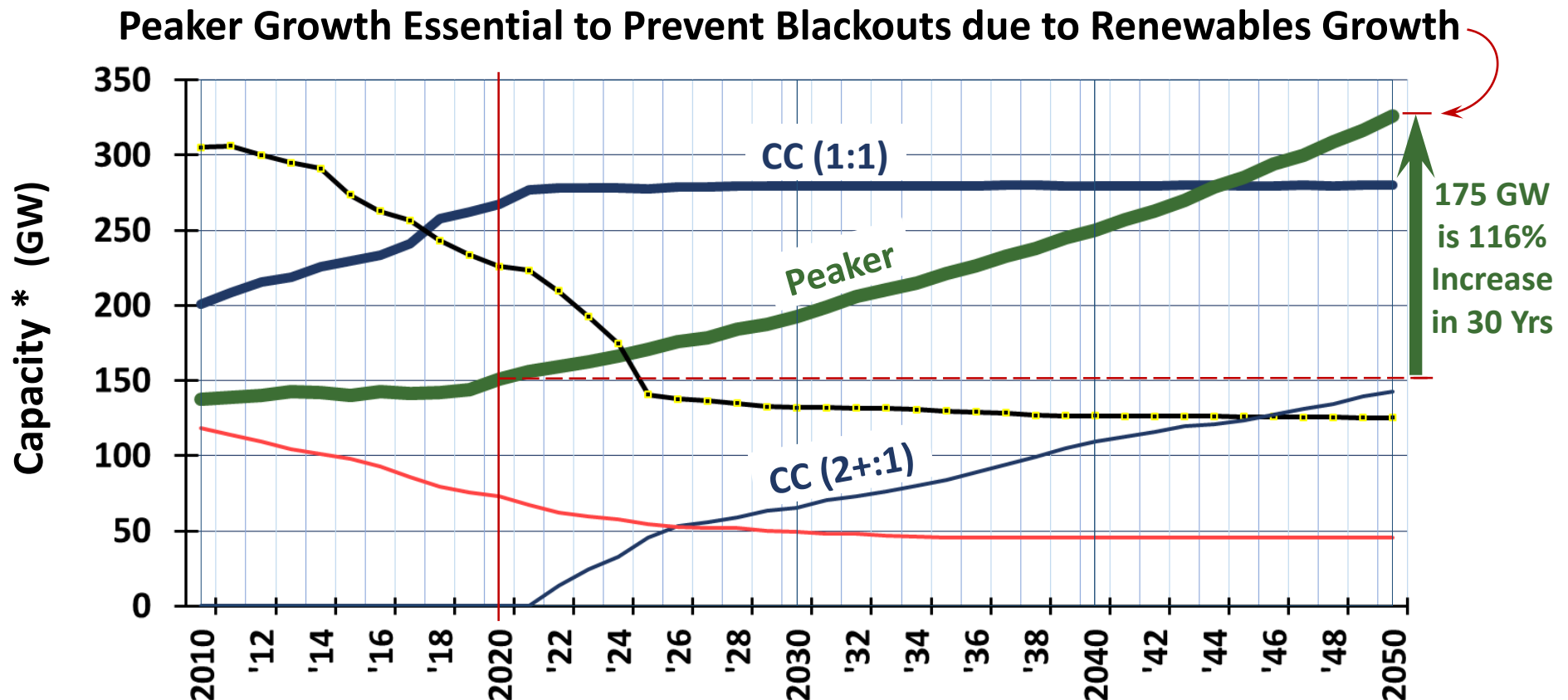
**With the  
Same Expander  
Same Pressure**



*\* VAST Produces ~70% More Electricity  
Depending on Pressure*

*\*\* VAST has 24% Higher Efficiency  
Consuming 19% Less Fuel  
Reducing CO<sub>2</sub> by 19%*

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



\* Name Plate  
Rating  
Installed Power

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

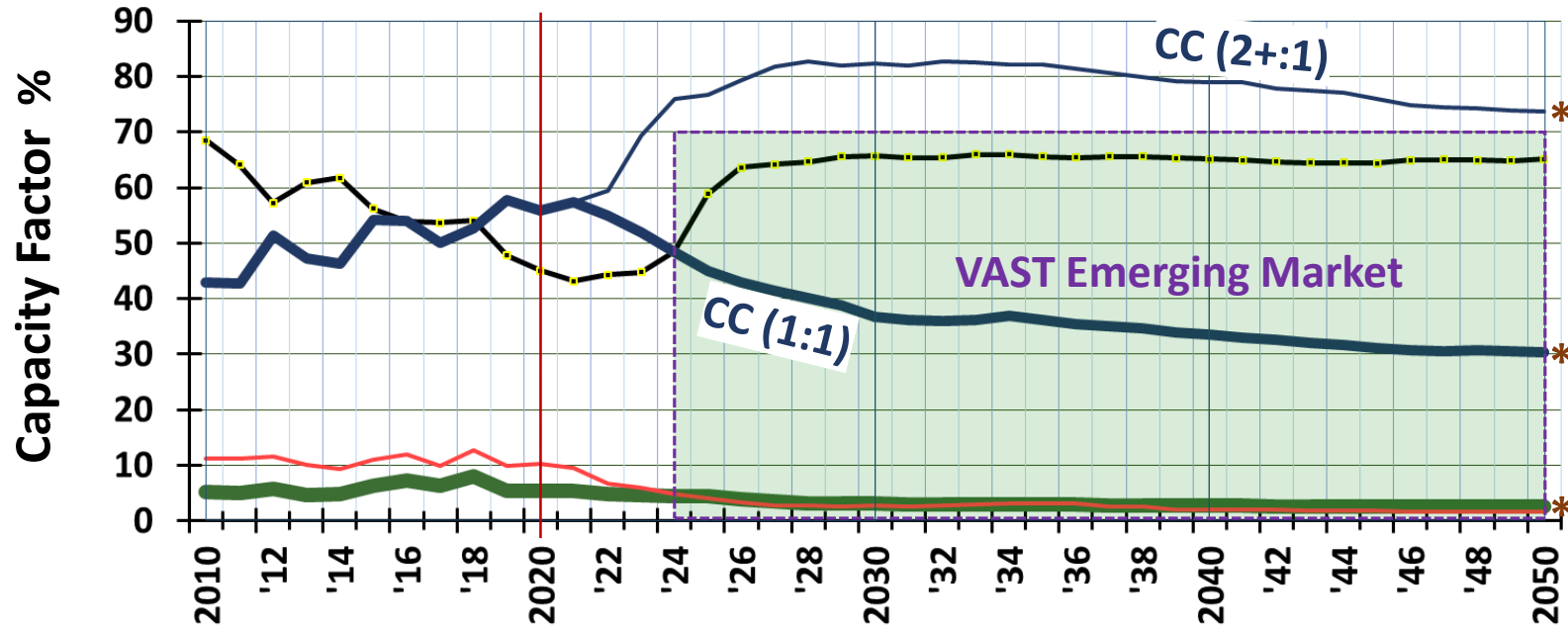
- Combined Cycle (1:1)\*\* Gas:Steam Turbine
- Peaker Gas Turbine
- Coal
- Combined Cycle (2+:1) Gas:Steam Turbine
- Oil or Gas Steam Turbine

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

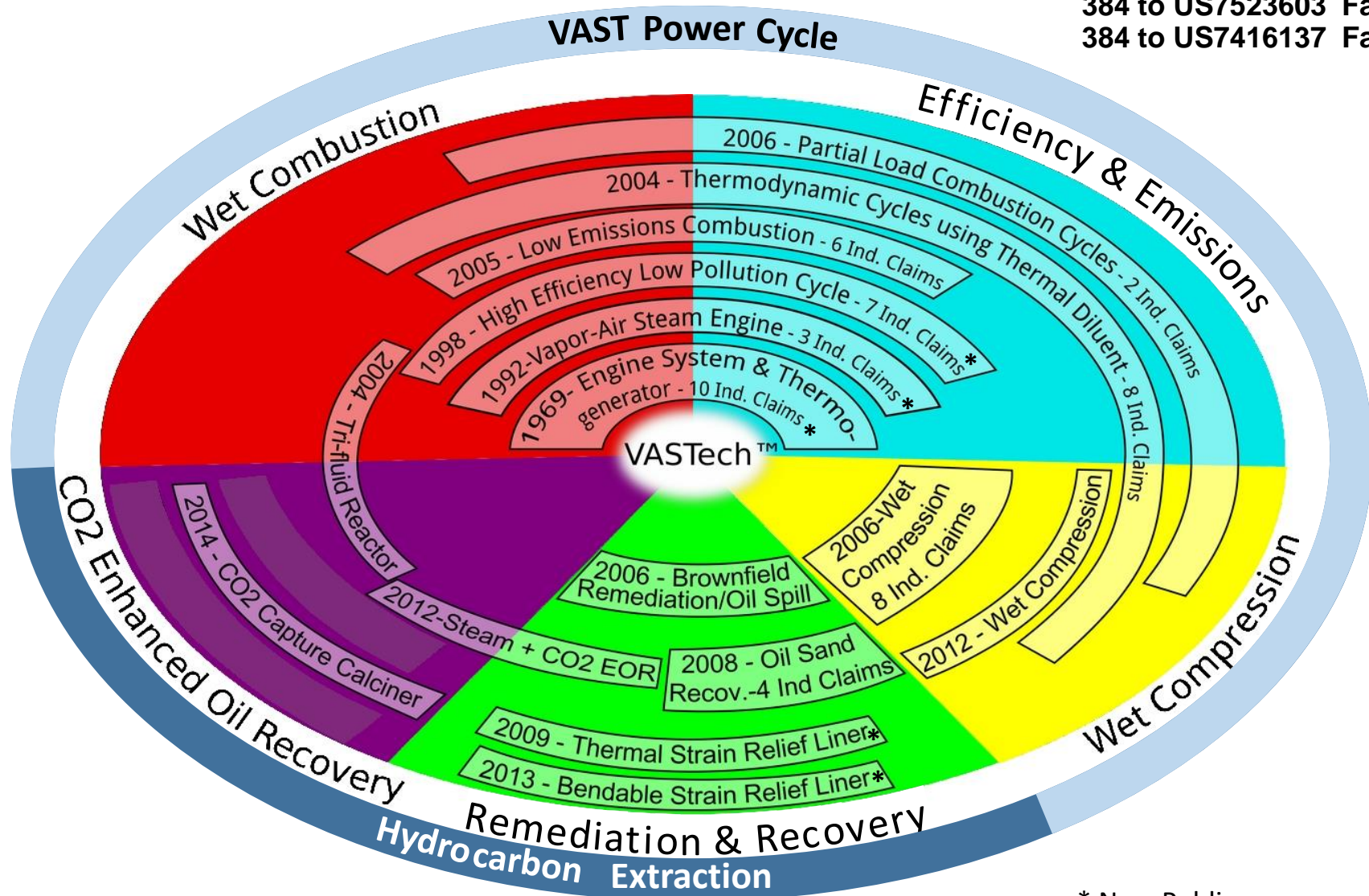
**\*\*1 Gas Turbine with  
1 Steam Expander**

# VAST Patent Portfolio - 34 Patents Worldwide

## 17 US Allowed Patents since 2004, others in preparation

1,238 Citations to  
VAST Patents & Applications

Highly Cited  
103 to US6289666 Patent  
384 to US7523603 Family  
384 to US7416137 Family



\* Now Public



# DOE Backs VAST with Expertise of 2 National Labs

VAST has Invested over \$8M Developing and Patenting the Core Power Technology

High Performance Computing for Manufacturing (HPC4Mfg) Grant

[hpc4mfg.llnl.gov](http://hpc4mfg.llnl.gov)

- \$300K DOE Award to support VAST's Combustor Optimization for 12 months
- \$360K VAST Contribution In-Kind: Labor and Expense

Argonne National Laboratory (ANL), Illinois

[www.anl.gov](http://www.anl.gov)

- Multidisciplinary Science and Engineering Research Center with US Dept. of Energy
- Ran CFD (Computational Fluid Dynamics) Modeling of 729 VAST Combustor variations
- Detailed Physics-based, Combustion and Fluid (Fuel, Air, Water, Steam) Flow Simulations for VAST Combustor Design Trade-offs
- Using powerful Supercomputer Arrays with State-of-the-Art Simulation Software

Lawrence Livermore National Laboratory (LLNL), California

[www.llnl.gov](http://www.llnl.gov)

- Multi-disciplinary RD&D Center on Weapons and Fusion Energy
- Develops System-wide Optimization using Neural Network Modeling
- Using Supercomputer Arrays with State-of-the-Art Modeling Software



# 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: Co-founder and Chairman

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

Gary helped found and 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: Co-founder and Chief Scientist

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: Chief Executive 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 \$5 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, Co-founder and Chairman

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John O'Halloran, Chief Executive Officer

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