# **VAST<sup>®</sup> Grid Edge Technologies**

Enabling Renewable Power

## VAST<sup>®</sup> TriFluid<sup>™</sup> Combustor VAST<sup>®</sup> FastRamp<sup>™</sup> Turbine VAST<sup>®</sup> Power Cycle

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### How Do We Keep The Lights On? VAST's Disruptive Solution

#### **The Problem**

- Prevent Renewable Grid Collapse & Blackouts
- Reduce Greenhouse Gases & other Emissions
- Current Technologies are Expensive

#### **The Solution**

- ➤ VAST Ultra-clean FastRamp<sup>™</sup> 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



**CALIFORNIA BLACKOUT** 



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<sup>™</sup> 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.



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24 -2013 GW (1,000 MW) 22 -2014 20 -2015 18 -2016 16 -2017 14 -20182019 12 2020 12am 3am 6am 9am 12pm 3pm 6pm 9pm 12am

### 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**



\* CARB - California Air Resources Board \*\* BACT - Best Available Control Technology \*\*\* CARB BACT ~2 ppm NOx at 15% O<sub>2</sub> using Exhaust Catalyst & Ammonia LAER - Federal Standard: Lowest Achievable Emission Rate



Value Added Steam Technologies Clean Power + Good Stewardship

#### **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



Clean Power + Good Stewardship

#### 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<sup>®</sup> FastRamp<sup>™</sup> Turbines enable >50% Renewable Power Grids



#### **Electrical Grid Stabilization Technologies**



POWER SYSTEMS, INC.

#### **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





#### **Performance Comparison**



\* VAST Produces ~70% More Electricity Depending on Pressure \*\* VAST has 24% Higher Efficiency Consuming 19% Less Fuel Reducing CO<sub>2</sub> by 19%

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



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

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\*\*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%	C3%	3%	3%
11%	10%	3%	2%	2%

Combined Cycle (2+:1) Gas: Steam TurbineCoal

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

Value Added Steam Technologies

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\*\*1 Gas Turbine with

**1** Steam Expander

#### VAST Patent Portfolio - 34 Patents Worldwide 17 US Allowed Patents since 2004, others in preparation





### DOE Backs VAST with Expertise of 2 National Labs

Phase 1 High Performance Computing for Manufacturing (HPC4Mfg) Grant

- \$300K DOE Award to support VAST's Combustor Optimization for 12 months
- Utilized 1 Million Core Hours of Supercomputer Run-time
- \$360K VAST Contribution In-Kind: Labor and Cash

Phase 2 High Performance Computing for Manufacturing (HPC4Mfg) Grant

- \$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

- 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

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



hpc4mfg.llnl.gov

hpc4mfq.llnl.qov

www.anl.gov

www.llnl.gov

#### 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 \$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?** 

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