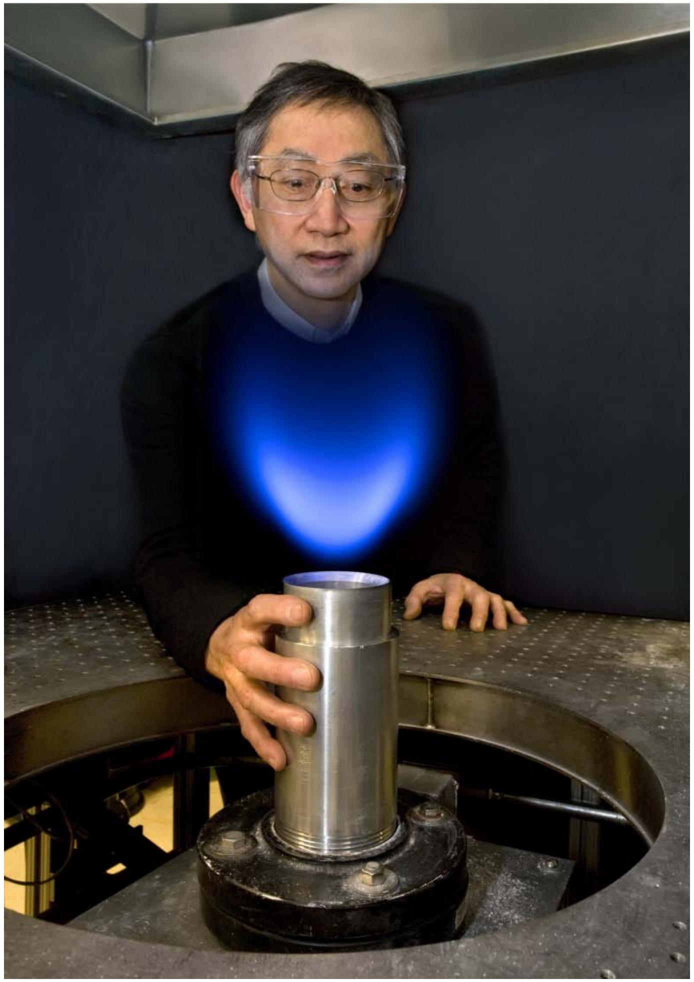
Ultra-Clean Low-Swirl Burner for Heating and Power Systems

Robert K. Cheng

Senior Scientist
Combustion Technologies Group
Environmental Energy Technologies Div
Lawrence Berkeley National Laboratory

http://eetd.lbl.gov/aet/combustion/LSC-info/
Voice: 510 486 5438, RKCheng@lbl.gov

What's Special About Low-swirl Burner?

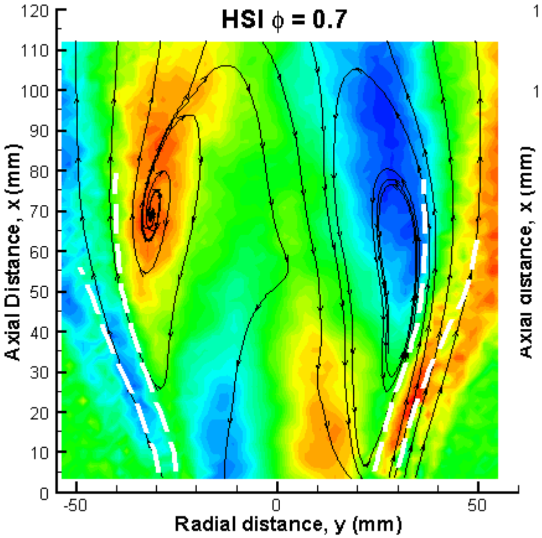


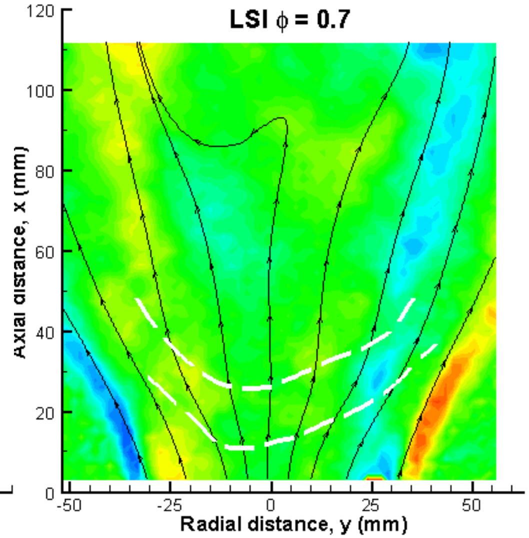
- LSB is a simple, yet sophisticated way to burn gaseous fuels (hydrocarbons & hydrogen) efficiently with ultra low NO_x emissions by a lower cost and durable burner

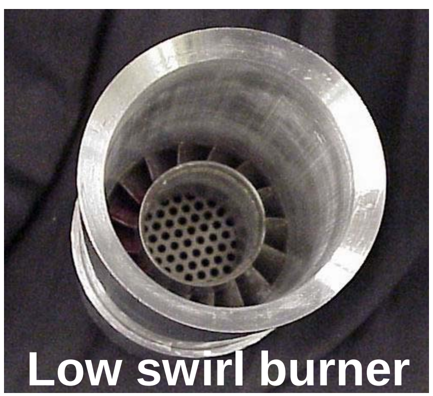
Unique Features

- **Spin-off from basic research**
- **Patented swirl nozzle generates flow divergence without recirculation**
  - Counter intuitive to conventional wisdom
- **Detached turbulent premixed flame**
  - Exploits a balance between diverging flow velocity and turbulent flame speed
  - Provides greater stability than conventional high-swirl designs
- **Minimal thermal stresses to burner**
  - Simple parts made of conventional materials without cooling circuits
- **Sound scientific foundation guiding engineering developments**
  - Turbulence intensity gives feedback for turndown
  - Coupling of flowfield similarity and turbulent flame speed controls flame dynamics

Increase Efficiency via a Simple Low Drag Design



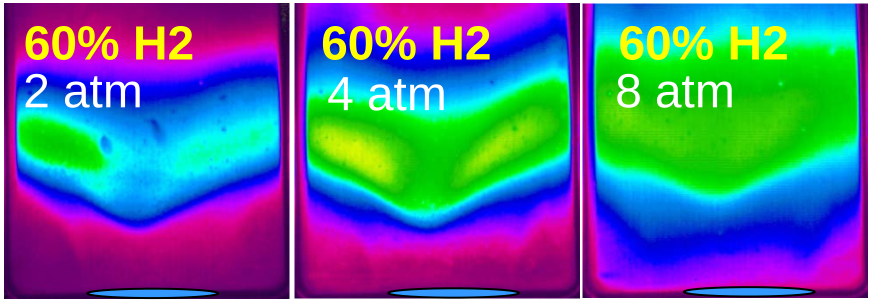


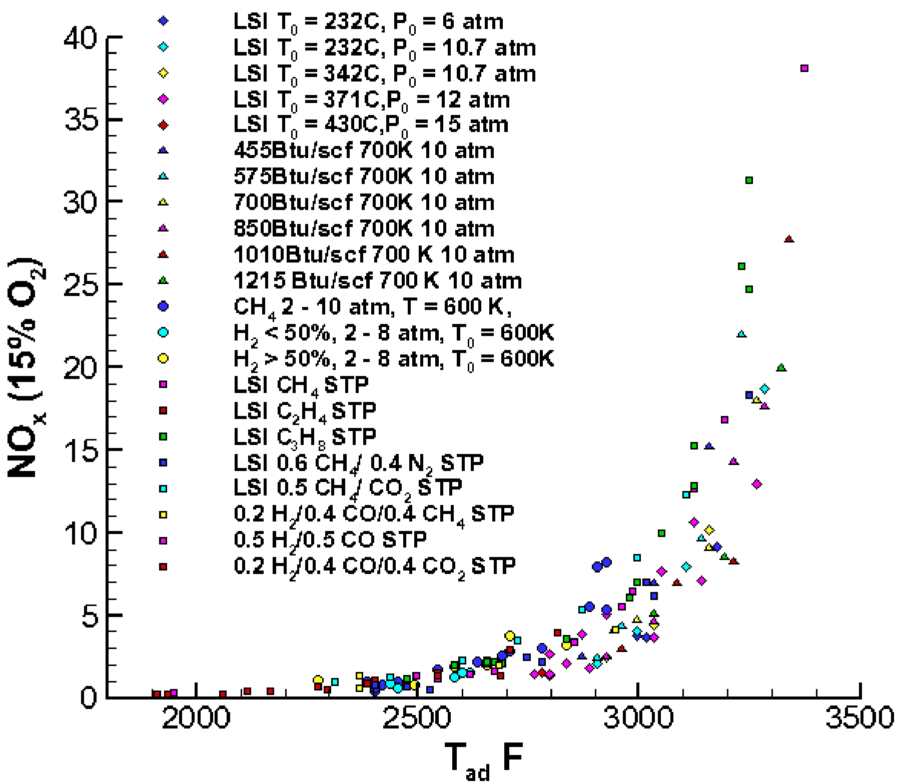


Flowfields of high-swirl burner and low-swirl burner show the absence of a recirculation zone reduce the shear stresses

- **Larger effective area than conventional high-swirl nozzles with improved flame stability**
- **Significant reduction in aerodynamic drag**
  - Absence of large intense recirculation zone
  - Small vane angle requirement
- **Opportunity to reduce ΔP/P in a gas turbine by 1 – 2%**
  - Similar gains for other gen-sets

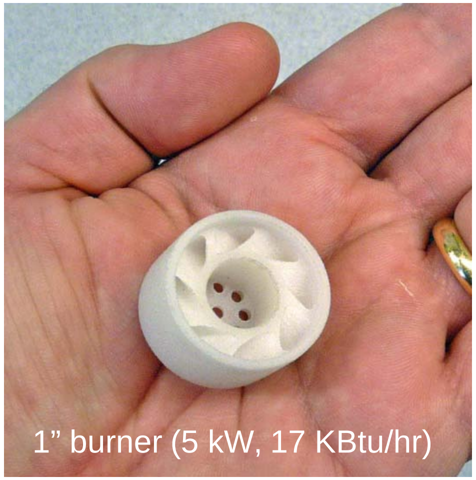
High Performance





- **Compact and stable flame**
  - operates at STP and T > 750F and P > 20 atm
- **Fuel-flexible**
  - all gaseous hydrocarbon fuels and hydrogen
- **High turndown 3 < U < 120 m/s**
  - Flame position unchanged
  - Extremely low flame oscillations
  - NO_x and CO functions of flame temperature only
- **Ultra-low NO_x**
  - exceeds Leonard Stegmaier limit
  - delivers higher temperatures without infringing on air quality rules
- **Ease of lighting off, startup, load following and shutoff**

Adaptable and Scalable

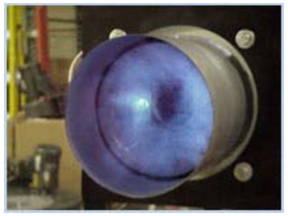

1” burner (5 kW, 17 KBtu/hr)

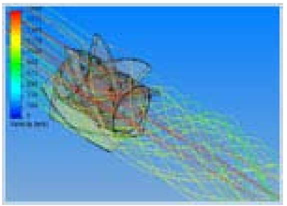

26” burner
(44 MW, 150 MBtu/hr)

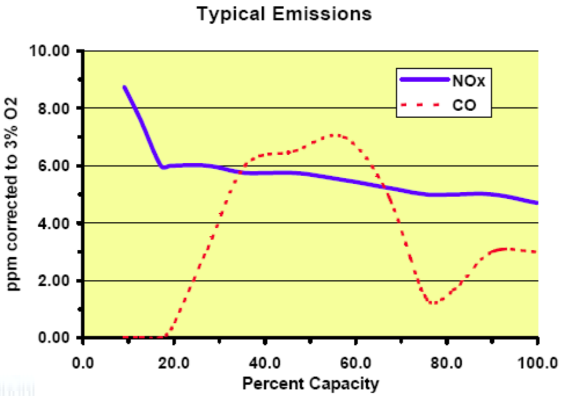
- **Scale by governing equations**
  - **Constant velocity scaling using swirl number criteria**
  - **Developed for 7 kW to 22 MW (0.7” to 22” diameter)**
- **Performance unaffected by swirl vane designs**
  - **Implemented with flat, curved, flat, thin and thick swirl blades for ease of manufacturing from conventional materials**
- **Retrofit to existing equipment**
  - **Small foot-print**
  - **Amenable to simple fuel injection scheme**
  - **Compatible with existing system controls**

Honeywell's Maxon Corp. LSB Product Lines

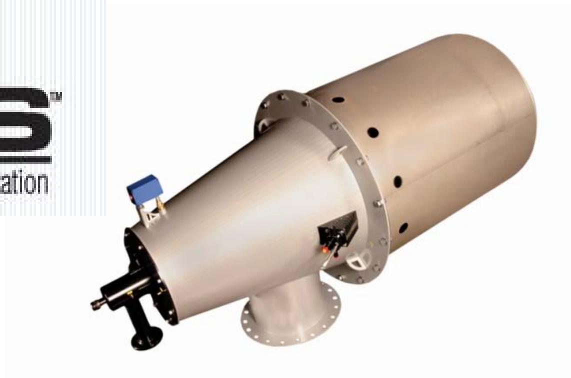
- Maxon commercialized LSB for industrial heating, baking, and drying (2003)
- "Achieved industry best emissions without sacrificing cost or performance"
  - 4-7 ppm NO_x (@3%O_2) guaranteed
- M-PAKT burners (0.5 – 3.5 MMBtu/hr) available since 9/03
  - Fuel flexible with natural gas, propane and butane
  - 10:1 turndown without pilot assistance
  - Hundred of units installed
  - Improve product quality (paint curing & food processing)
  - 1st unit operating continuously since 2/02
- OPTIMA SLS gas/liquid dual-fuel burners (12 - 50 MMBtu/hr) introduced in 2006
  - 8", 10", 12", 16" & 22" burner diameters
  - enhanced 13:1 turndown
  - backup liquid fuel firing
  - Units installed & in production



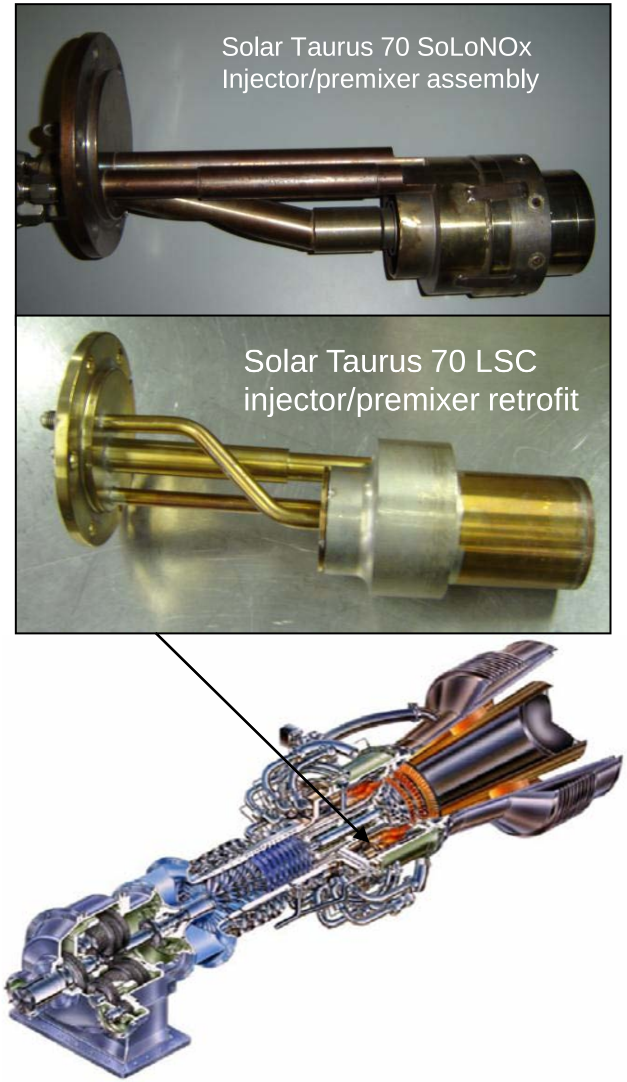




SLS™ shear layer stabilization



LSB Retrofits for Ultra Low-emission Gas Turbines



- **DOE EERE Project metrics**
  - **< 5 ppm NO_x (@ 15% O_2)**
  - **Transition to back-up fuels**
  - **Durable for at least 8000 hours**
  - **No more than 10% cost add-on than typical Dry-low-NOx system**
  - **No negative impacts on gas turbine performance**
- **Developed "drop-in" retrofit for 7.7 MW Taurus 70 engine**
  - **Simple design built from existing parts**
  - **No special requirements for materials and control**
  - **Exceptional in engine performance (< 5 ppm NO_x)**
  - **Potential for efficiency improvement**
- **Featured article in Gas Turbine World Vol. 36 No. 6 Nov. – Dec. 2006**
- **2007 RD100 award winner**

Development and Commercialization Status

Applications	Status
Industrial oven and process heaters	Commercialized for 300,000 Btu/hr to 100 MMBtu/hr
Residential and commercial water heaters	Developed and lab. tested Seeking commercialization partner
Residential and commercial “warm air” furnaces	Developed and lab. tested Seeking commercialization partner
Industrial water boilers	Developed and lab. tested Seeking commercialization partner
Industrial steam boilers	Seeking development partner
Industrial process fluid heaters	Commercialized
Microturbines (< 200 KW)	Field demonstrated in an Elliott TA100, being developed for digester gas operation in a Capstone C65
Industrial gas turbines (< 10 MW)	Developed and engine tested
Utility gas turbines (> 100 MW)	Rig tested

Attributes of LSB for Gen-set

- **Demonstrated LSB combustion process provides high power density, small system foot-print**
  - **Flame volume much smaller than catalytic and highly preheated and highly diluted combustion systems**
  - **LSB much shorter than many gas turbine dry-low NOx burners**
- **Demonstrated fast start up, shut down, and load change**
  - **in rig-tests of LSB prototypes for gas turbines of 7 – 200 MW**
- **Demonstrated ultra-low emissions**
  - **in an Elliott T100 and Solar T70 fitted with LSB**
  - **at full and part loads in rig-tests of LSB prototype for utility size gas turbine**
- **Demonstrated LSB operates on traditional and opportunity fuels without hardware change**
  - **in rig-tests of LSB prototype and laboratory experiments**
  - **results published in five archival journal papers**

Exploiting the Full Potential of Low-swirl Burner

- Gen-sets developed with LSB in mind will
  - improve efficiency by a low drag design
  - increase turndown by a robust flame stabilization mechanism
  - lower emissions by enabling stable ultra lean burn
  - reduce capital cost by simple manufacturing using conventional materials
  - reduce operating cost by lower material degradation rate and conventional controls

LSB Cross-cut to small-scale DG Technology Platforms

- Proven technology for microturbine – Elliott TA100 with LSB in operation since 2008, to be adapted to Capstone C65 for digester gas operation
- Ready for integration with hybrid systems
- Optimal for ramp-up heat, and flaring of residual exhaust fuels for solid oxide fuel cells
- Ready as DG external heat source
  - Quick turndown for responsive load tracking to attain higher efficiency in Sterling engine and similar systems without infringing on emissions

Publications

Littlejohn, D., Cheng, R. K., Noble, D. R. and Lieuwen, T. (2010). Laboratory Investivations of Low-Swirl Injector Operating with Syngases. *J. of Eng. for Gas Turbines and Power,* **132**, 011502-011510.

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