Validation of Catalytica Technology on the Grid at SVP

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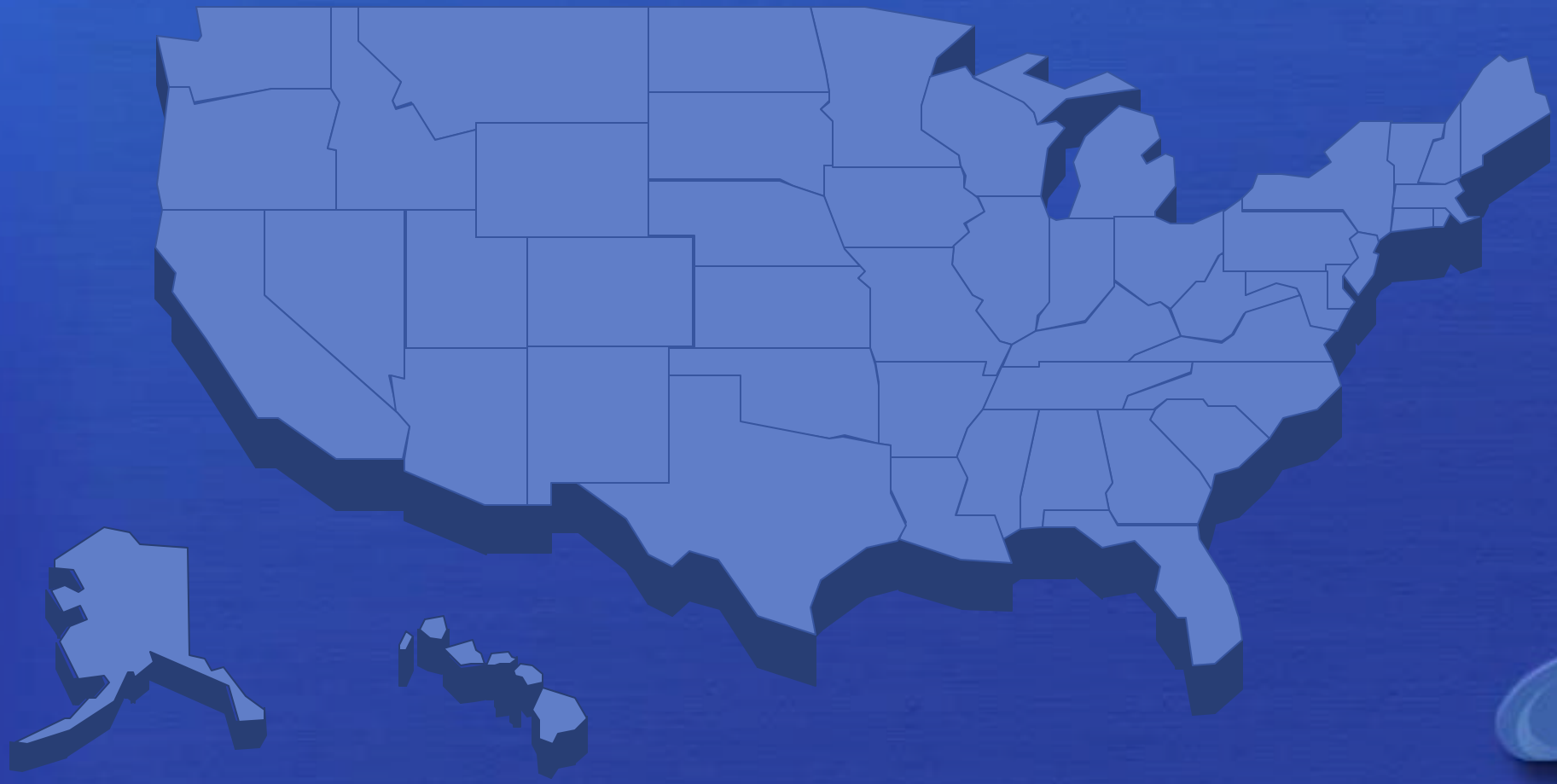
Frequently Asked Questions

- Why is it so important that catalytic combustion be developed for gas turbines?
- What are the traditional options for limiting NOx and why aren't they good enough?
- What is a catalyst and how does catalytic combustion work?
- Why has Catalytica been successful where others have failed?
- What is our current state of development?

1985

NOx Emissions Limits

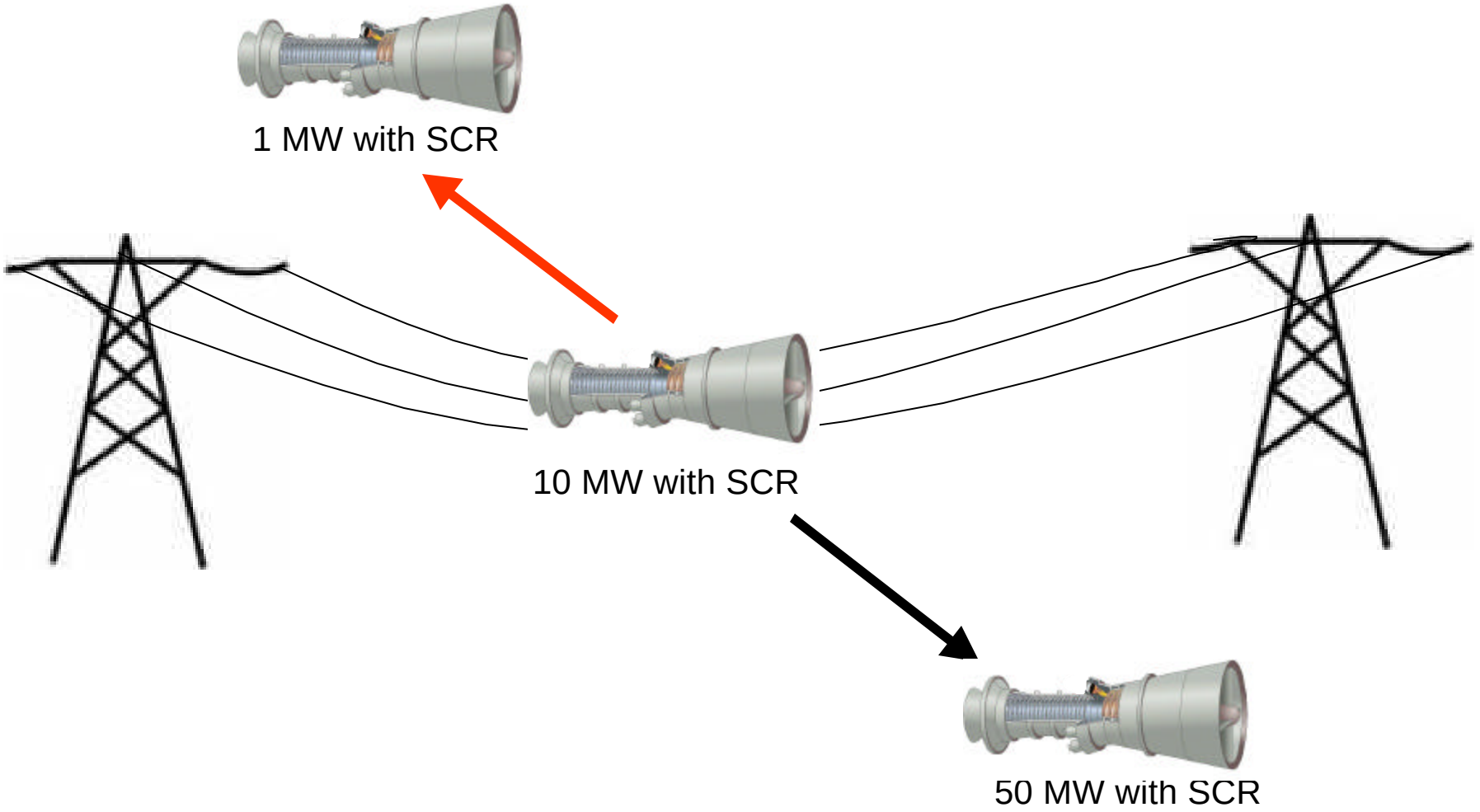
> 25 ppm



California Cogen Market
Under 20 MW Gas Turbine

*Information obtained from Caterpillar® Solar Turbines

Cost Consequences of SCR

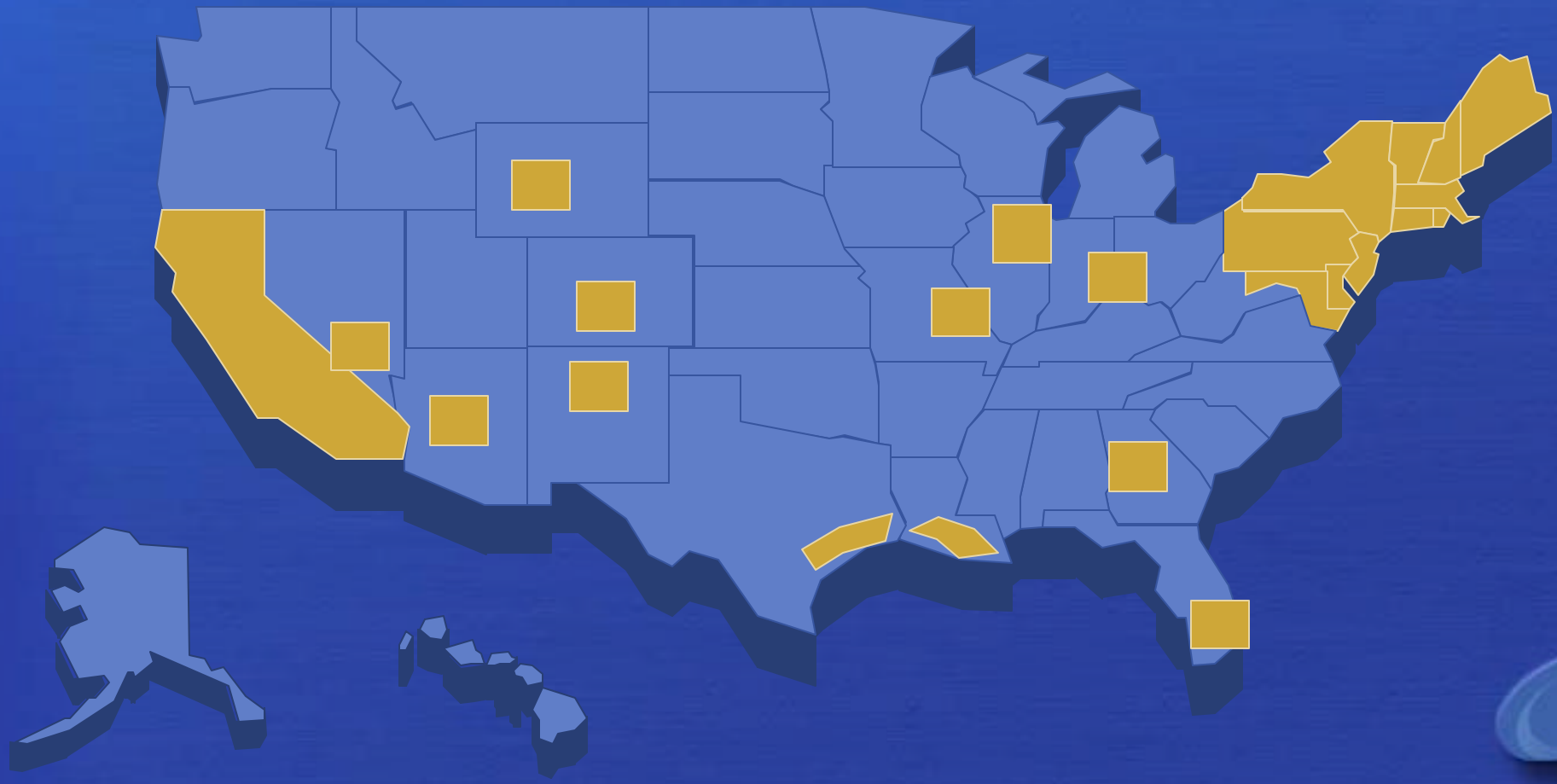


1999-2000

NOx Emissions Limits

> 25 ppm

< 5 ppm

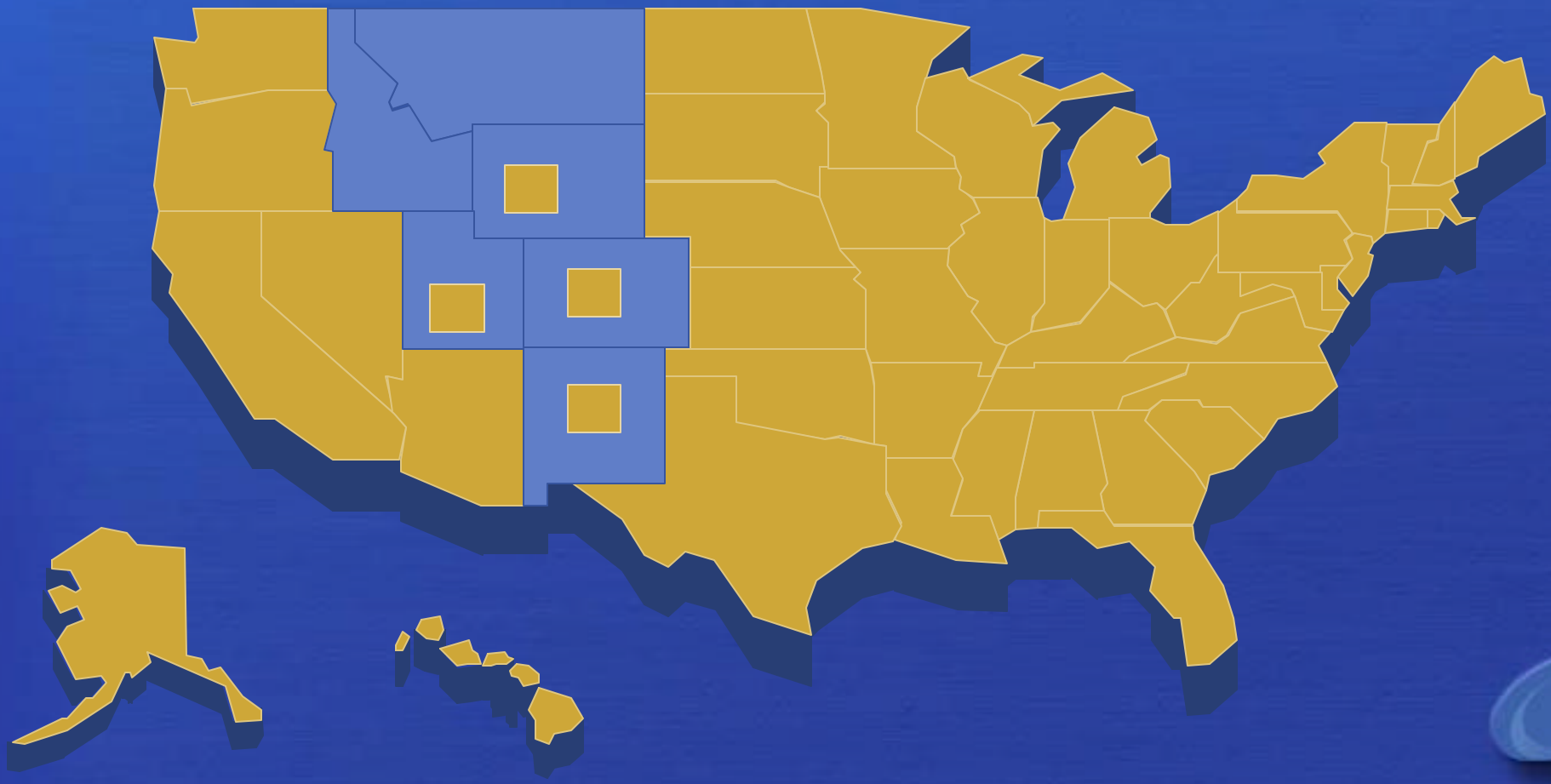


2005

NOx Emissions Limits

> 25 ppm

< 5 ppm



What are the traditional options for limiting NOx and why aren't they good enough?

Traditional Options for Limiting NOx Emissions

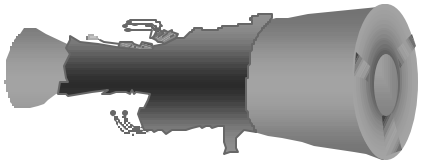
- Inject water or steam diluent to decrease flame temperatures
  - Insufficient impact (25 ppm)
  - Expensive water processing

- Operate at lowest possible flame temperature (“lean premix”)
  - Practical limit: ~15 ppm NOx
  - Unstable flame causes machine vibrations

- Remove NOx from exhaust stream
  - Selective Catalytic Reduction (“SCR”)
    - Uses ammonia
    - Very costly to install and operate
  - SCONOX
    - Very costly to install and operate

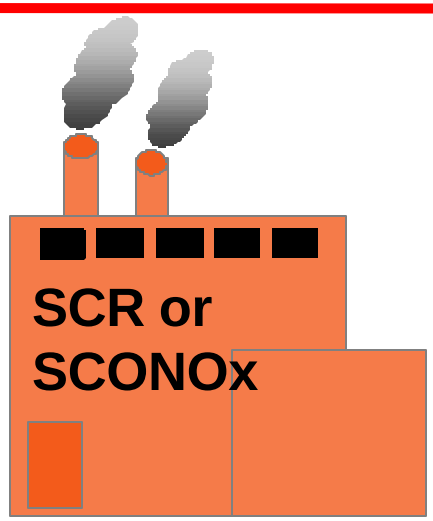
Perspective on the options

Conventional Turbine



+ Water injection
Steam injection
Lean premix

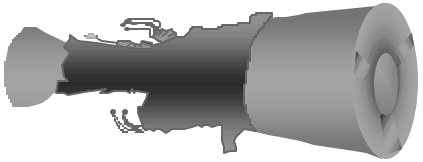
+



Cleanup

→ **Less tha**
>3 ppm

Catalytic Combustor Turbine



→ **Less than 2.5 ppm**

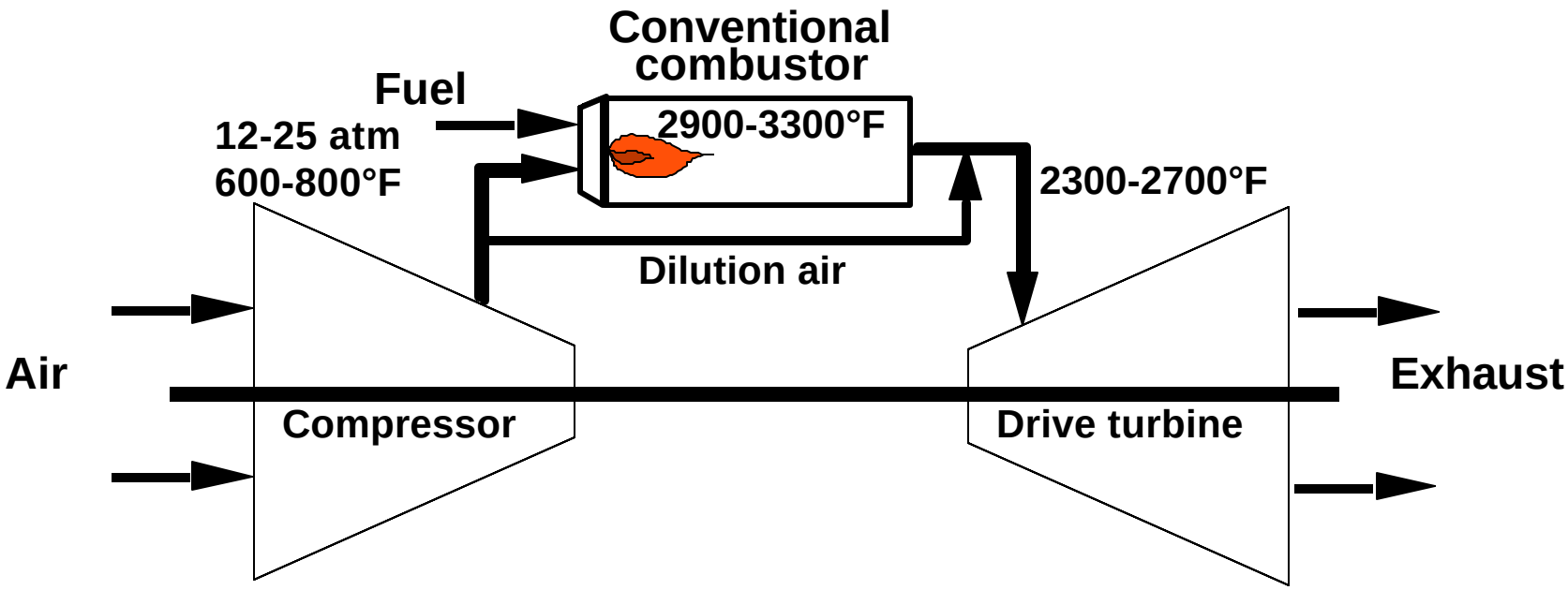
What is a catalyst and how does catalytic combustion work?

What is a Catalyst?

- A substrate that:
  - Increases the Rate of a chemical reaction
  - Directs a reaction
  - Is not consumed or changed in the process

In short, a catalyst facilitates breaking of bonds so a reaction can occur with lower activation energy.

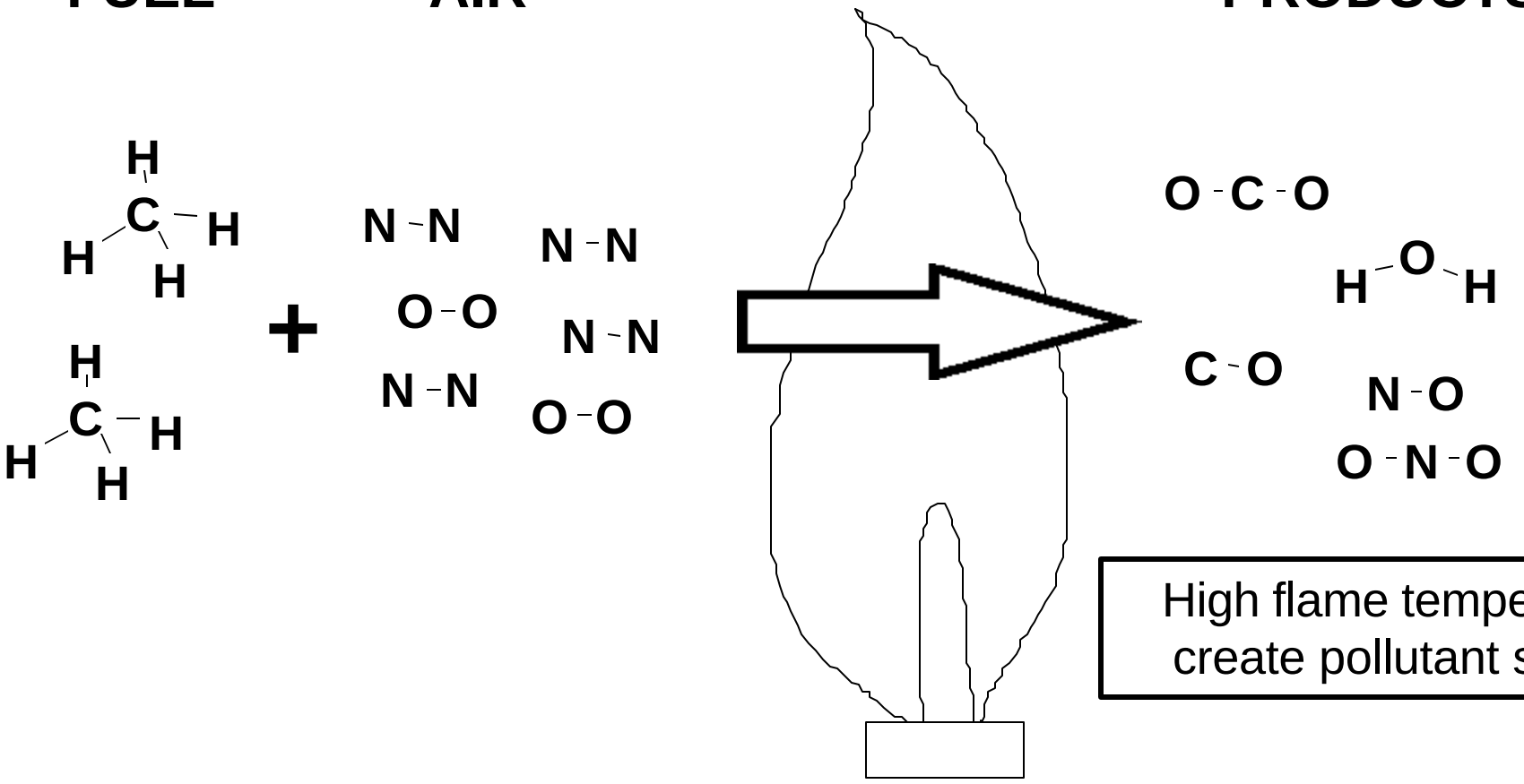
Conditions in conventional combustors



Localized combustion ⇨ $T_{flame} >> T_{turbine\ inlet}$

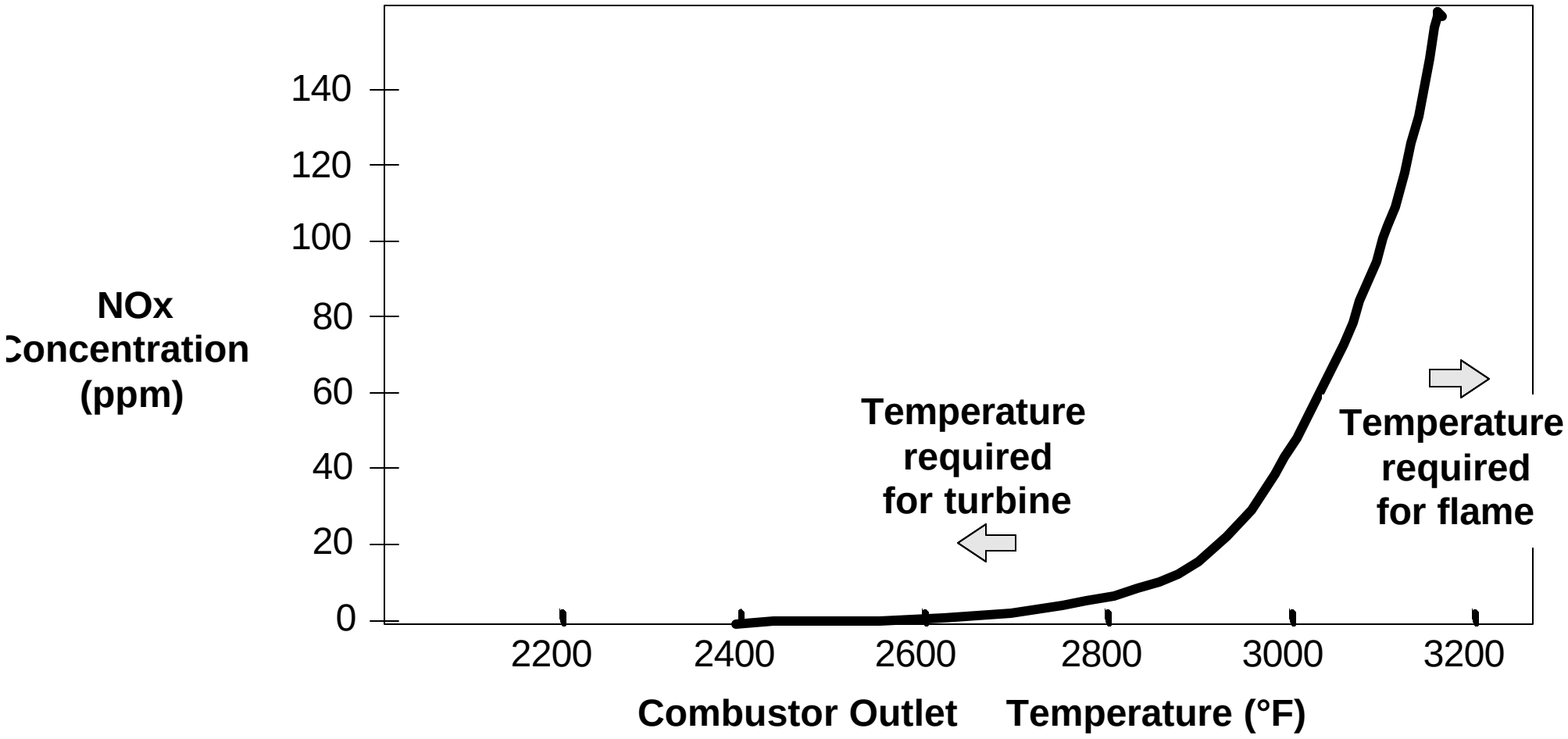
Challenge of flame chemistry

FUEL **AIR** **PRODUCTS**

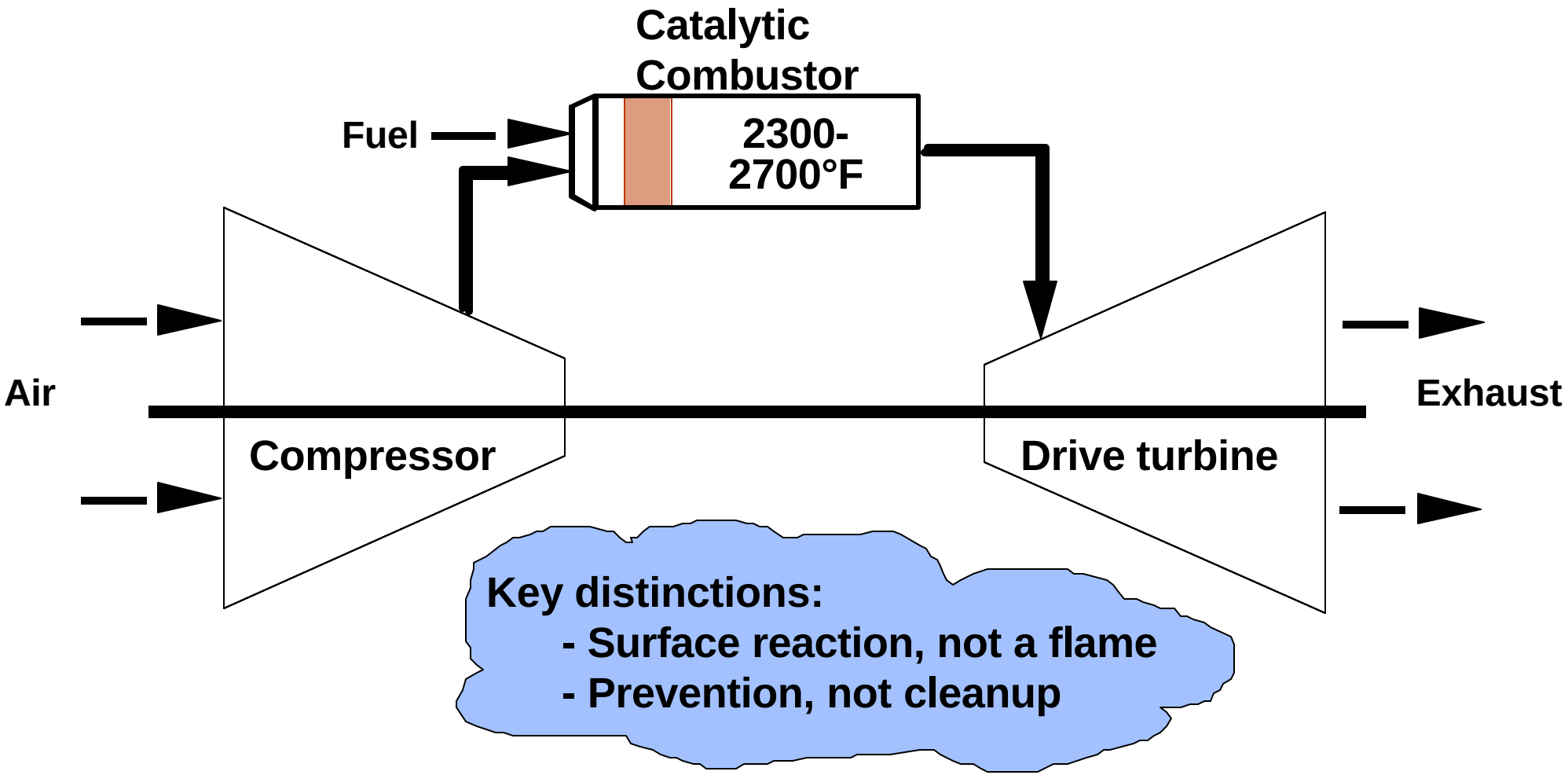


High flame temperatures create pollutant species

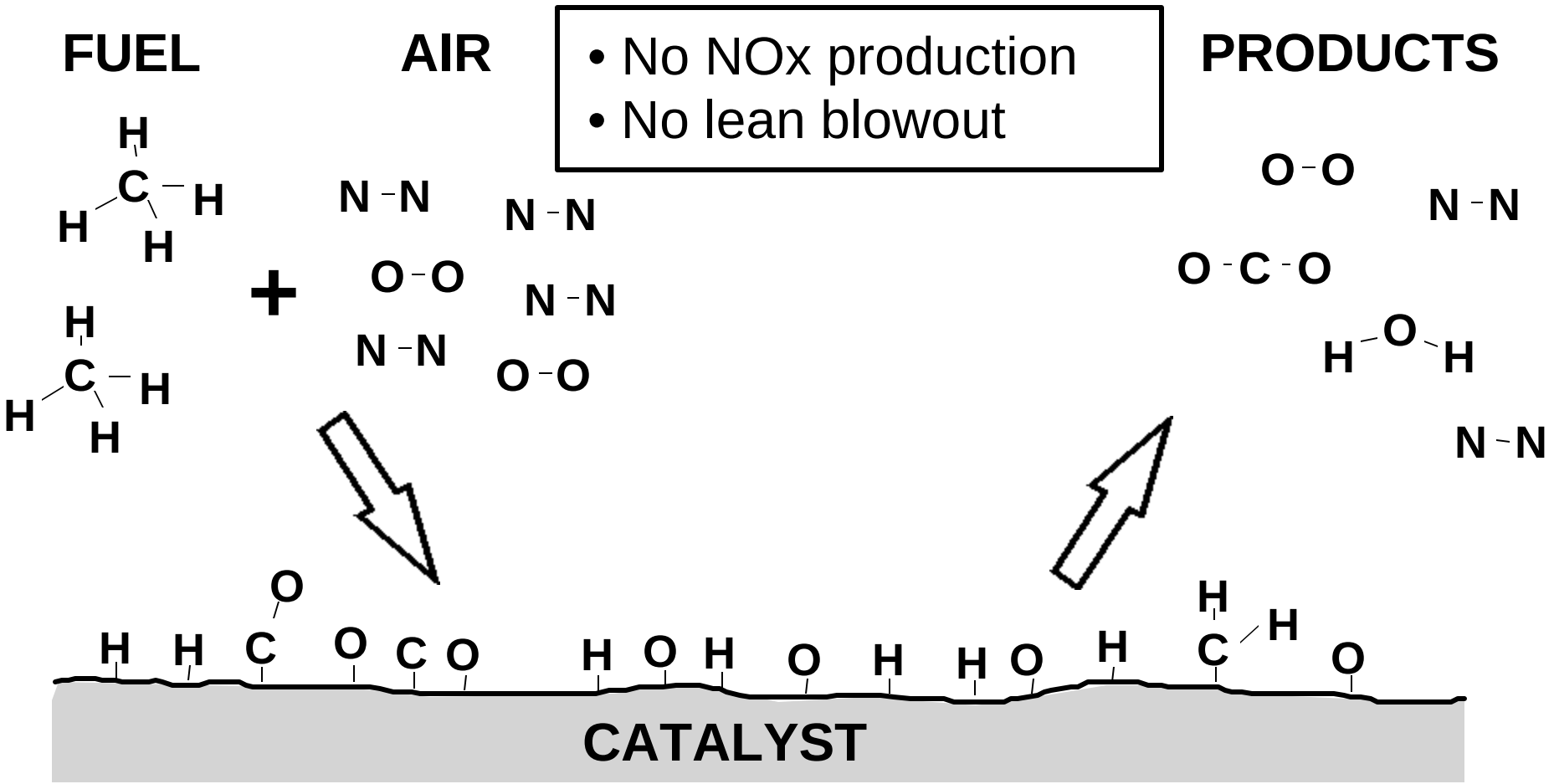
High temperatures cause high NOx levels



Conditions in Catalytic Combustor

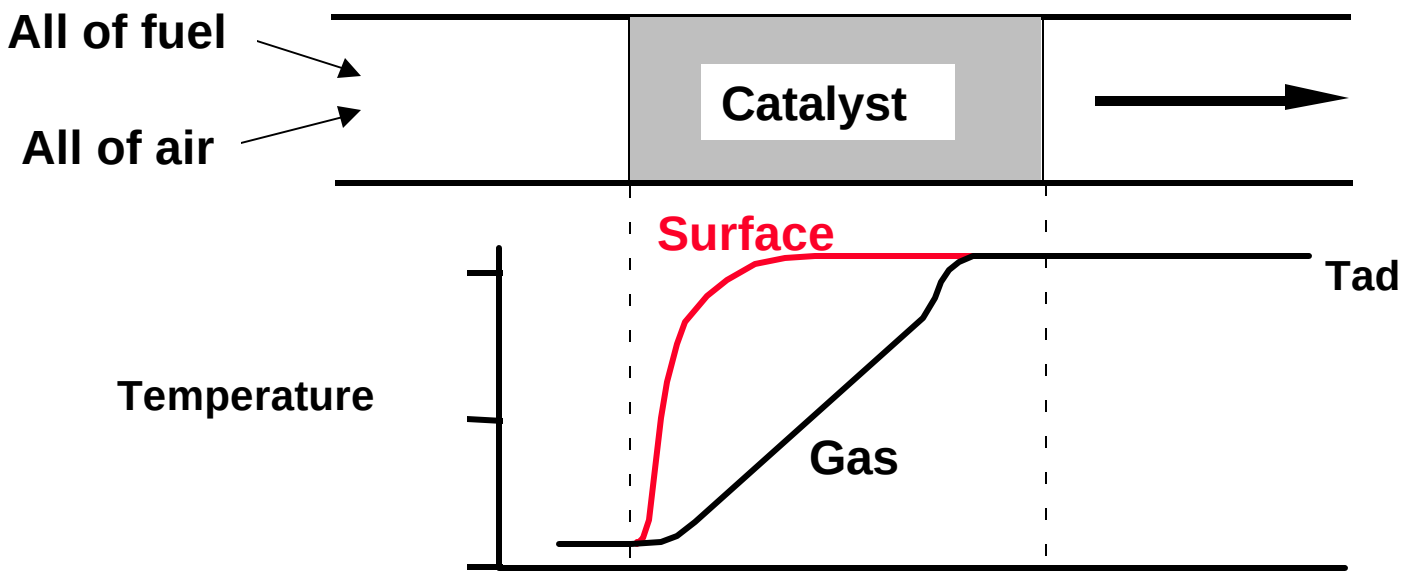


Advantages of catalytic chemistry



Why has Catalytica been successful where others have failed?

Barriers to traditional approaches



High surface temperature ⇨ Poor durability

⇨ Thermal shock fracture

Creativity:

To see what everyone else sees, and to think what no one has thought before…

Albert Einstein

XONON Technology

Chemical Thermostat

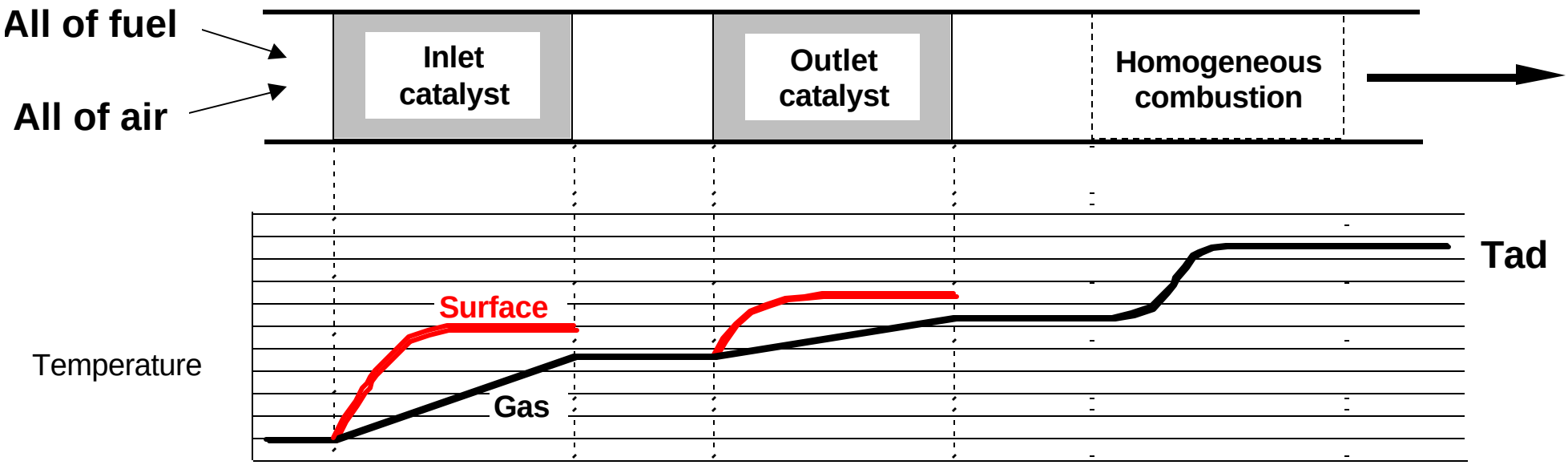
- **Palladium can be either oxide or metal in the catalyst**
- **The PdO-- Pd distribution is governed by thermodynamics:**
- **At any fixed O_2 partial pressure, the temperature determines whether Pd is oxide or metal**

$$PdO \underset{\text{Low Temp}}{\overset{\text{High Temp}}{\rightleftharpoons}} Pd + \frac{1}{2} O_2$$

- **PdO has high activity for methane oxidation; Pd metal has low activity**

➡ **Provides a thermostat to control the catalyst activity**

Alternative: XONON's staged approach



Staged catalyst

⇨ Limited surface temperatures

⇨ Catalyst separated from Tad

⇨ High firing T's accessible

Xonon

Cool Combustion

- *Breakthrough technology*
- *Pollution prevention versus clean-up*
- *Replaceable component*
- *Multiple industry applications*

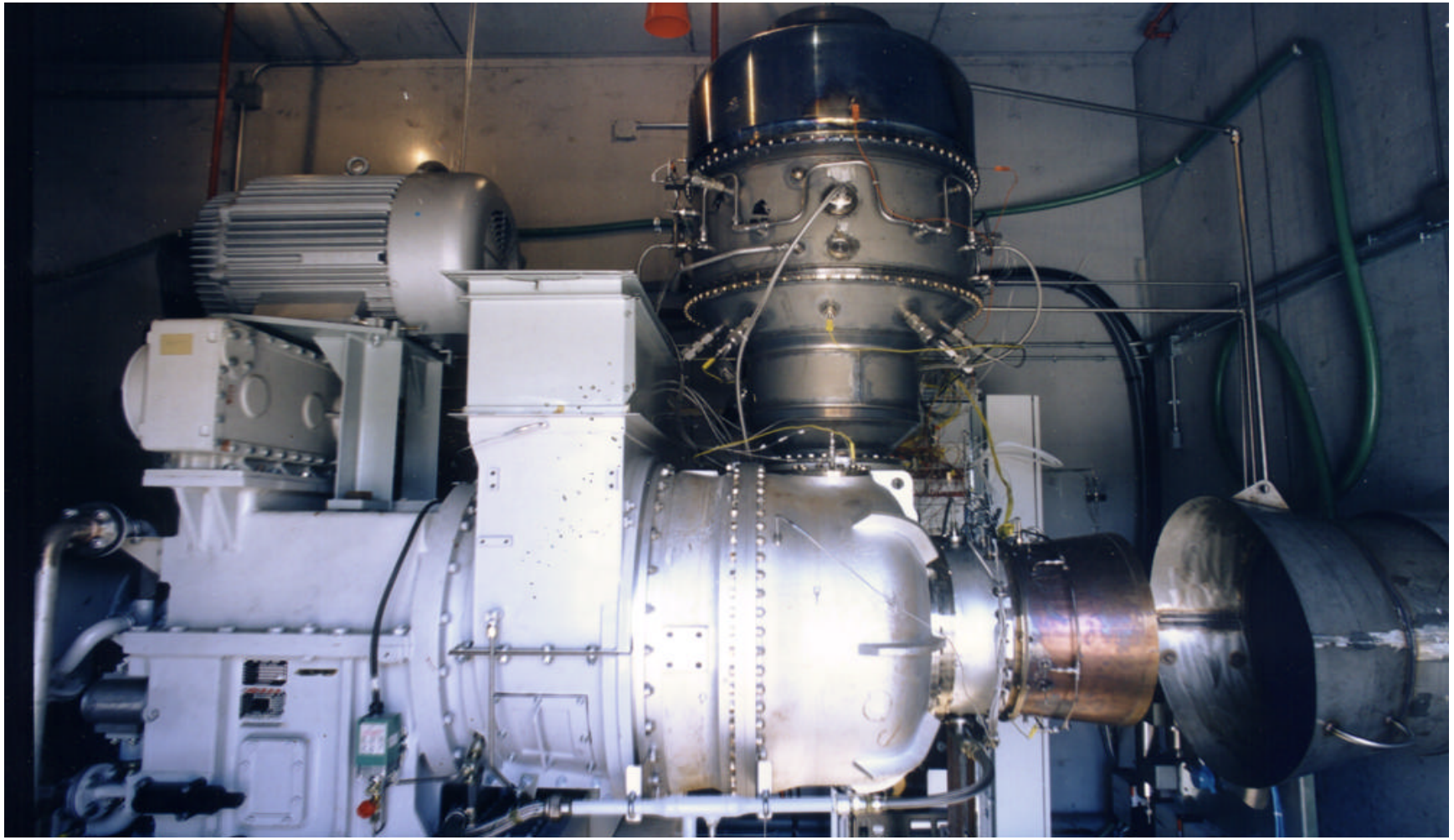
What is our current state of development?

Field test facility at Silicon Valley Power

- Kawasaki M1A-13A engine
  - Commercial package including enclosure, generator, etc.
  - Connected to electrical grid
- Objectives
  - Field demonstration
  - Run “around the clock” to obtain maximum hours
  - Engine test facility for combustor component improvements
  - RAMD program

Installation at Silicon Valley Power

KHI M1A-13A with Demonstrator Combustor



RAMD Test At Silicon Valley Power

- Reliability, Availability, Maintainability, Durability
- Run 8000 hours on the grid
- Co-funded by:
  - California Energy Commission (CEC)
  - Department of Energy (DOE)
  - California Air Resources Board (CARB)
  - Gas Research Institute (GRI)
  - Electric Power Research Institute (EPRI)

Technology status

- Catalytic combustion is being demonstrated in practice
- Aspects of demonstration include:
  - Power delivery to grid
  - Low emissions
  - 7-day, 24-hour operation
  - Unattended operation
  - Long run-time
  - Uniform temperature profile
  - Minimal vibrations and noise

XONON Emissions performance

Through first 3000 hours:

- NOx < 2.5 ppm
- CO < 6 ppm
- UHC < 6 ppm

(All values corrected to 15% O_2)

Attractions of Catalytic Combustion

- Ultra-low emission levels
- Prevention vs. clean up
- No toxic by-products
- Applies to all turbine sizes (24 kw - 250+ MW)
- Applies to new and installed turbines
- No flame instability and associated vibrations
- No change in:
  - compressor or turbine sections
  - turbine firing temperatures