ADVANCED CATALYTIC STUDIES FOR POWER ENGINEERING AND ENVIRONMENTAL PROTECTION

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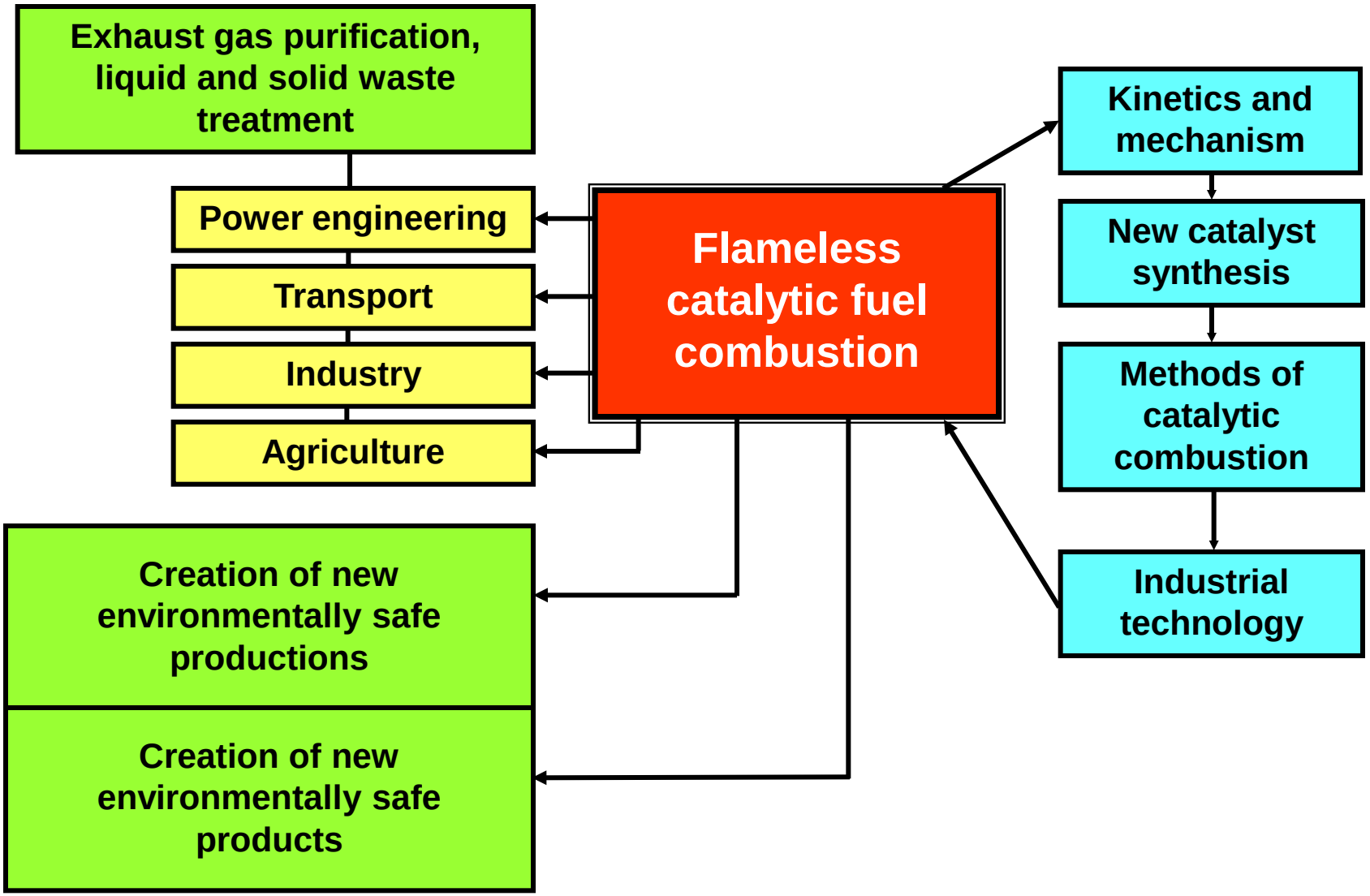
CONTENTS OF THE LECTURE

- Introduction
- Catalytic combustion
- Catalytic heaters
- Catalytic boilers
- Catalytic fluidized bed combustion
- Catalytic two-stage combustion
- Catalytic combustion for Gas Turbines
- Fuel Cells

CATALYSIS FOR POWER ENGINEERING AND ENVIRONMENT



KEY ROLE OF CATALYSIS

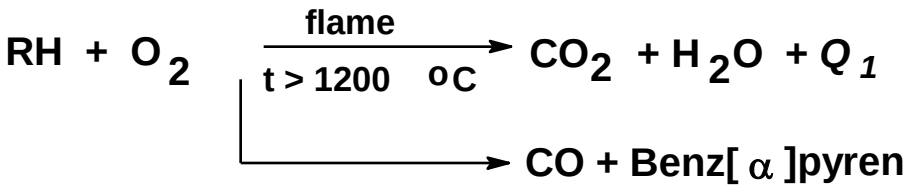
- Fuel production - 100%
- Fuel combustion - >0,1%
- Fuel cells - 100%
- Exhaust abatement - 80%

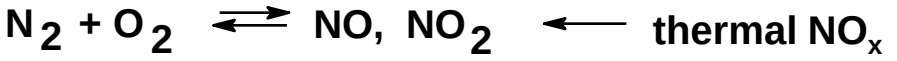
CATALYSIS FOR POWER ENGENEERING

- Increase combustion efficiency
- Improve environmental protection

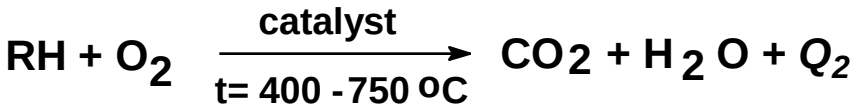
FUEL COMBUSTION

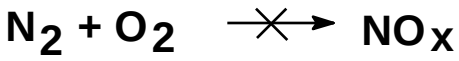
Traditional Combustion (Chain Mechanism)

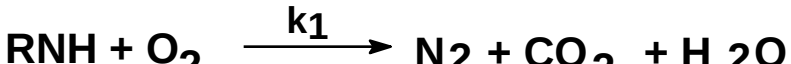


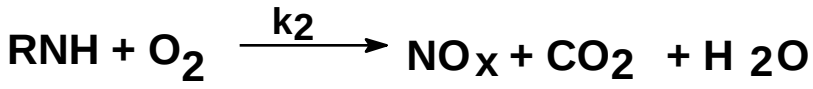


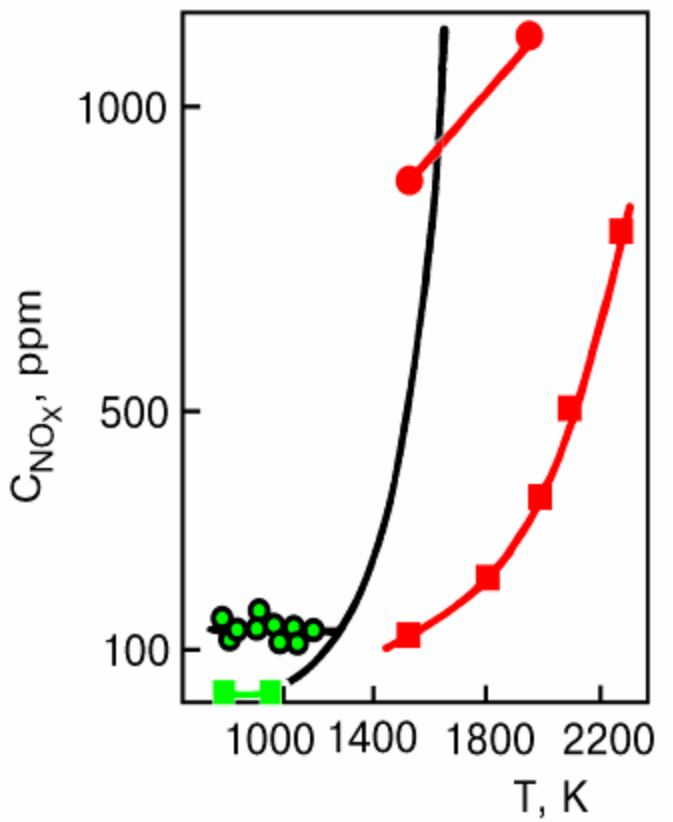
Heterogeneous Catalytic Oxidation (Low Temperature Flameless Combustion)











Dependence of NO_x concentration on temperature at combustion of fuel containing 1 wt.% of bound nitrogen:

Flame combustion
(● - fuel NO_x, ■ - thermal NO_x)
Catalytic combustion
(● - fuel NO_x, ■ - thermal NO_x)
— equilibrium NO_x concentration

Advantageous Fields of Catalytic Combustion Development

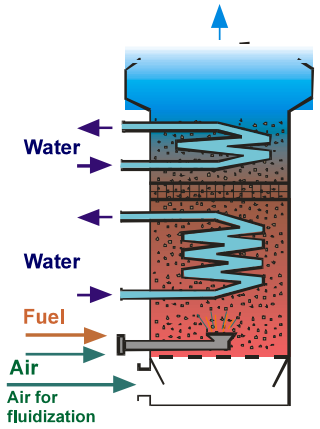
- **Greenhouse effect**
  - energy saving industrial technologies based on catalytic combustion, to diminish CO_2 formation.
- **Environmentally safe transport**
  - new generation of engines on the principles of catalytic fuel combustion;
  - catalytic purification of automotive exhaust:
  combustion of hydrocarbons, CO, aldehydes, soot particles, etc.
- **Environmental problems of energy production**
  - catalytic combustion in gas turbines and boilers;
  - catalytic fluidized bed combustion;
  - two-stage catalytic combustion;
  - catalytic space heaters, household appliances.
- **VOC Control**
- **Environmental impact of oil and gas mining, transportation**

MAIN APPLICATIONS OF CATALYTIC FUEL COMBUSTION

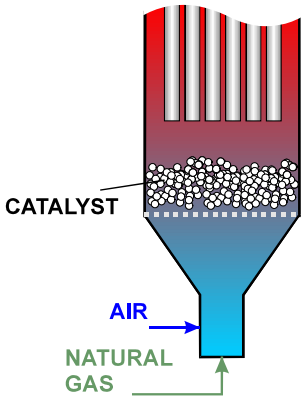
- Catalytic gas heaters
- Boilers
- Two-stage combustion
- Gas turbines
- Fuel cells

TYPES OF CATALYTIC BURNERS

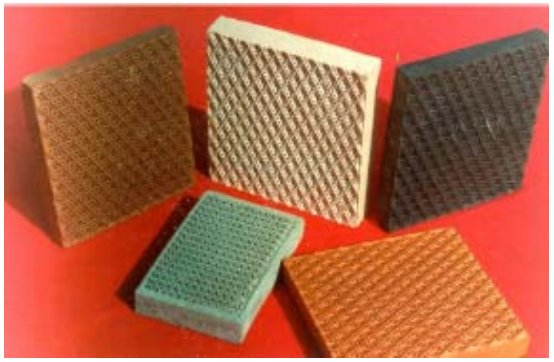
1. Fluidized bed (CHG)



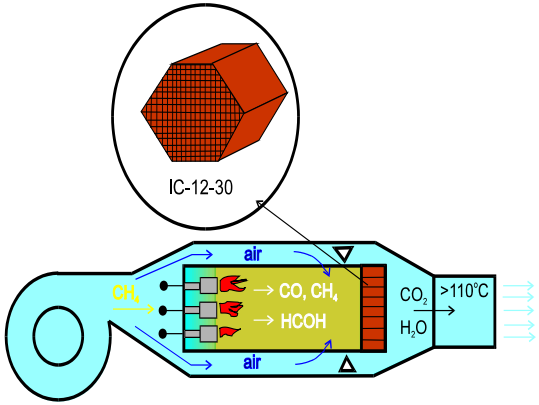
2. Fixed bed



3. Ceramic monolith honeycomb catalysts



4. Two-stage combustion



5. Foam material catalysts

(diameter - 300 mm)

CATALYTIC GAS HEATERS

Catalyst support

- **Fiber materials**
- **Ceramic monoliths**

Active component

- **Low ignition temperature**
- **High thermal stability**

Catalytic Gas Heaters «Termokat»

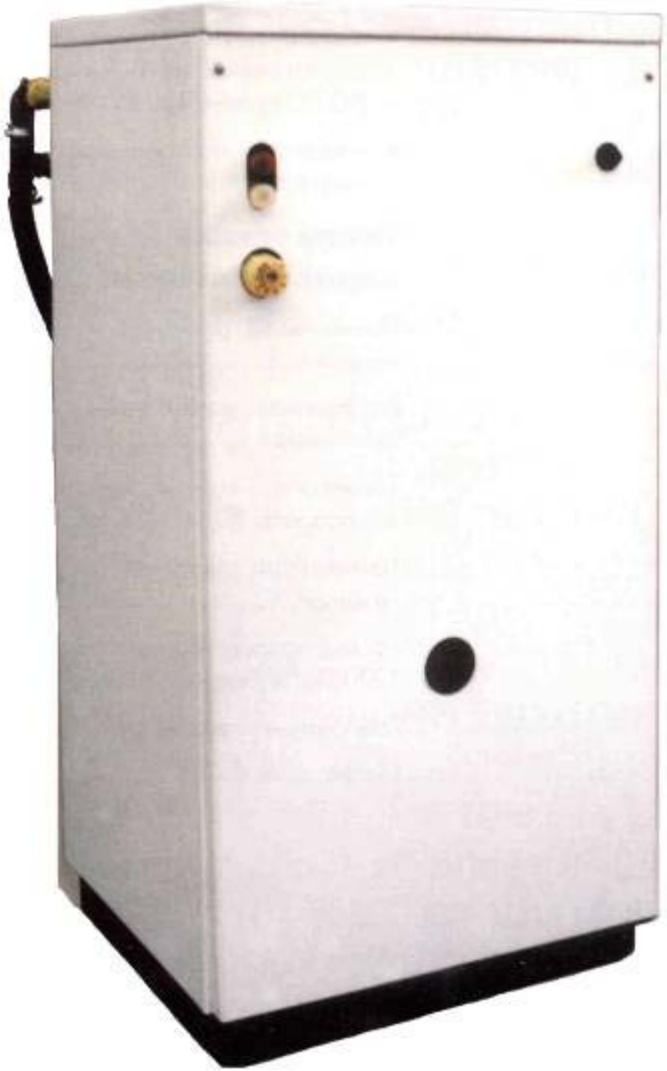
CATALYTIC BURNER

Mn containing catalyst
on highly porous foam material,
diameter 300 mm

CATALYTIC COMBUSTION GAS BOILER

Distinctive features:

- Full combustion of natural gas;
- No nitrogen oxides in the exhaust;
- Carbon oxide concentration is below 0,01 vol. %.

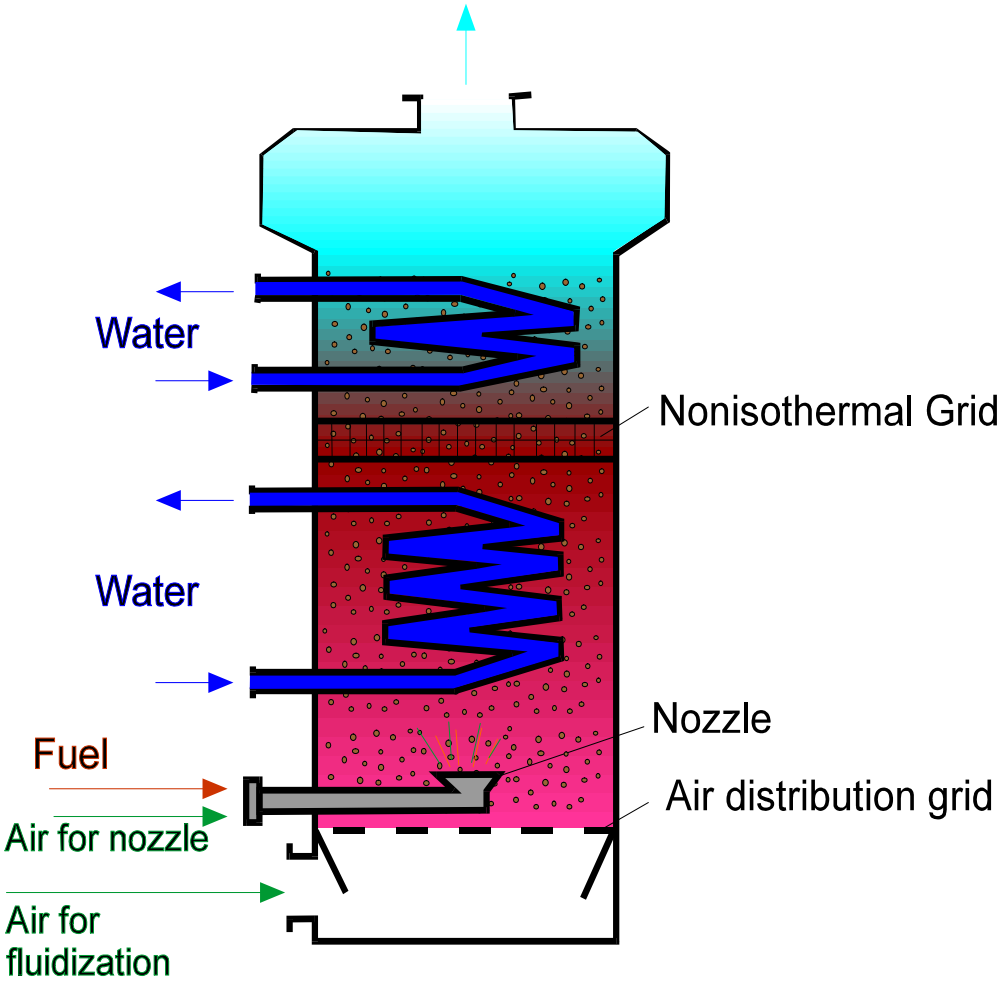


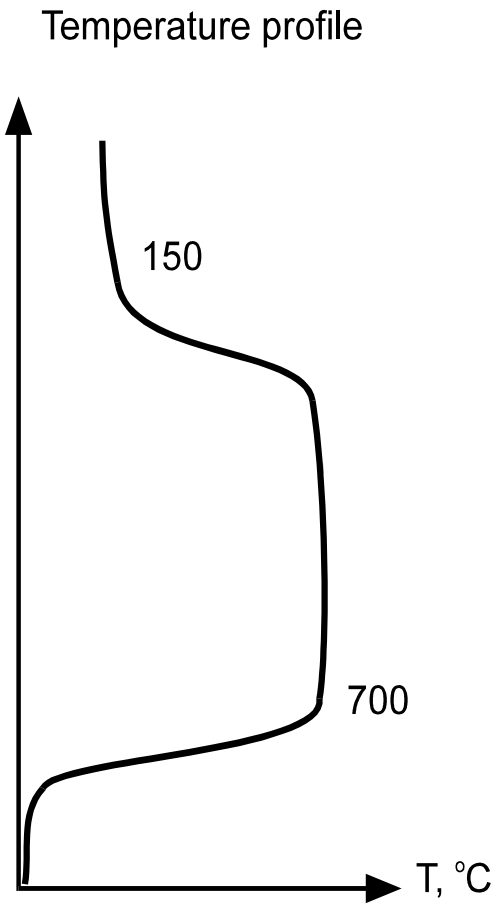
Technical characteristics:

Rated heat power, kW.....	**16**
Efficiency, %	**88-94**
Water temperature at the output, °C	**50-90**
Flue gas temperature, °C, not less	**110**
Natural gas consumption at 1270 Pa pressure, m^3/hour	**1.6**
Dimensions, mm	**890x440x440**
Mass, kg.....	**90**

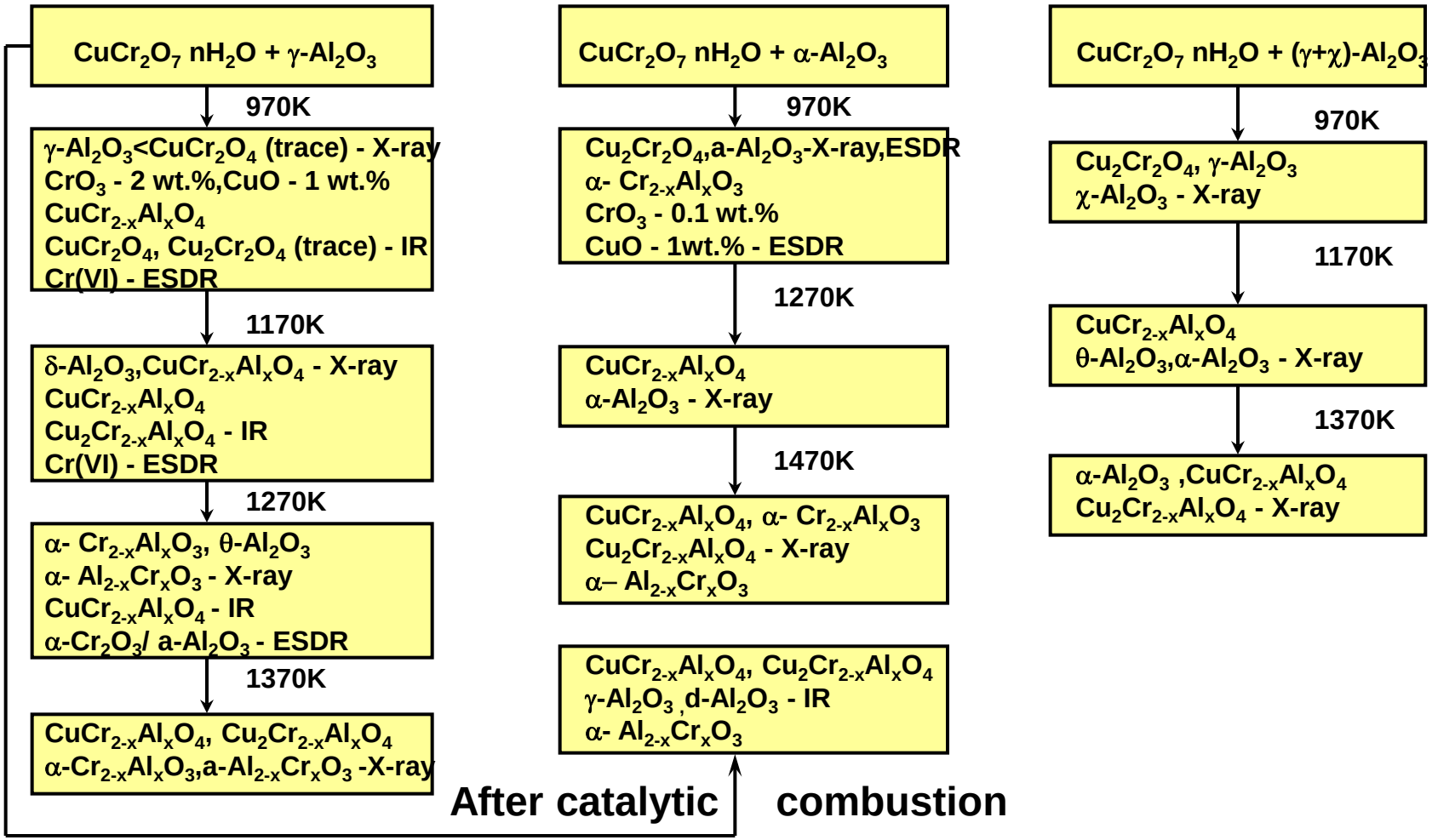
Fluidized Bed Catalytic Combustion

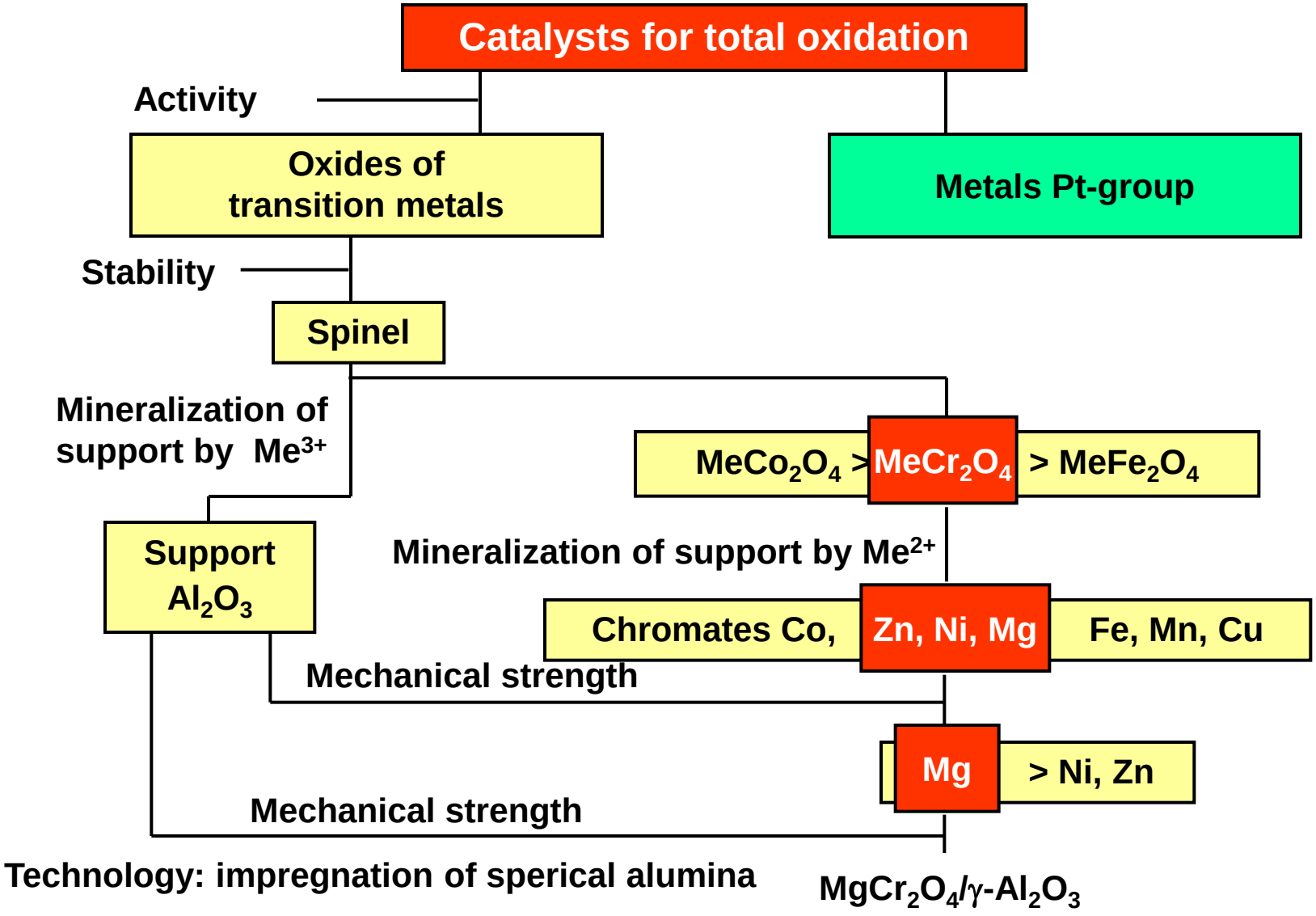
Schematic of Catalytic Heat Generator





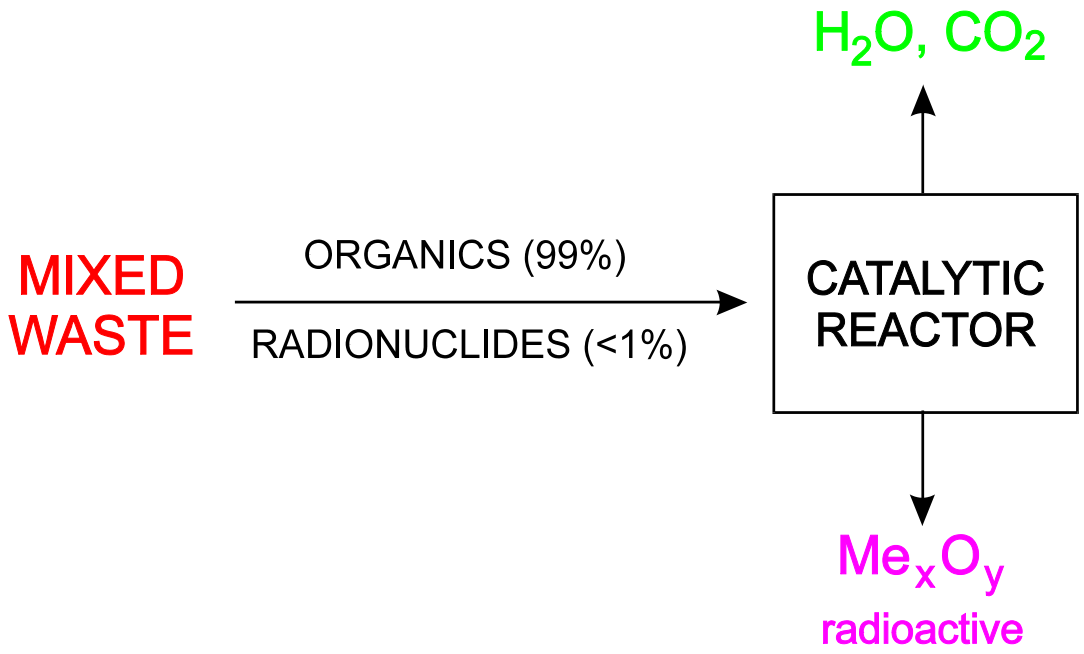
Scheme of Phase Transitions in Supported Copper-Chromium Catalyst




Catalysts for total oxidation
Activity
Oxides of transition metals
Metals Pt-group
Stability
Spinel
Mineralization of support by Me^{3+}
$MeCo_2O_4$ > $MeCr_2O_4$ > $MeFe_2O_4$
Support Al_2O_3
Mineralization of support by Me^{2+}
Chromates Co,
Zn, Ni, Mg
Fe, Mn, Cu
Mechanical strength
Mg
> Ni, Zn
Mechanical strength
Technology: impregnation of sperical alumina
support heat treatment, calcination.
$MgCr_2O_4/\gamma$-Al_2O_3

Catalytic Destruction of Mixed Organic Radioactive Wastes

- **complete destruction of hazardous organic components without secondary emissions**
- **compacting, more than 10000 fold reduction of volume of radioactive waste for further processing by existing technologies, vitrification**



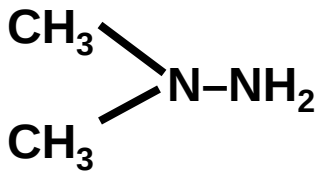
PROTOTYPE DEMONSTRATION PLANT FOR MIXED ORGANIC WASTE TREATMENT AT THE PLANT OF CHEMICAL CONCENTRATES, NOVOSIBIRSK

Catalytic reactor

Catalytic fluidized bed destruction of toxic rocket fuel

Objective

Environmentally safe and efficient utilization of an extremely toxic and explosive rocket fuel 1,1-dimethylhydrazine:

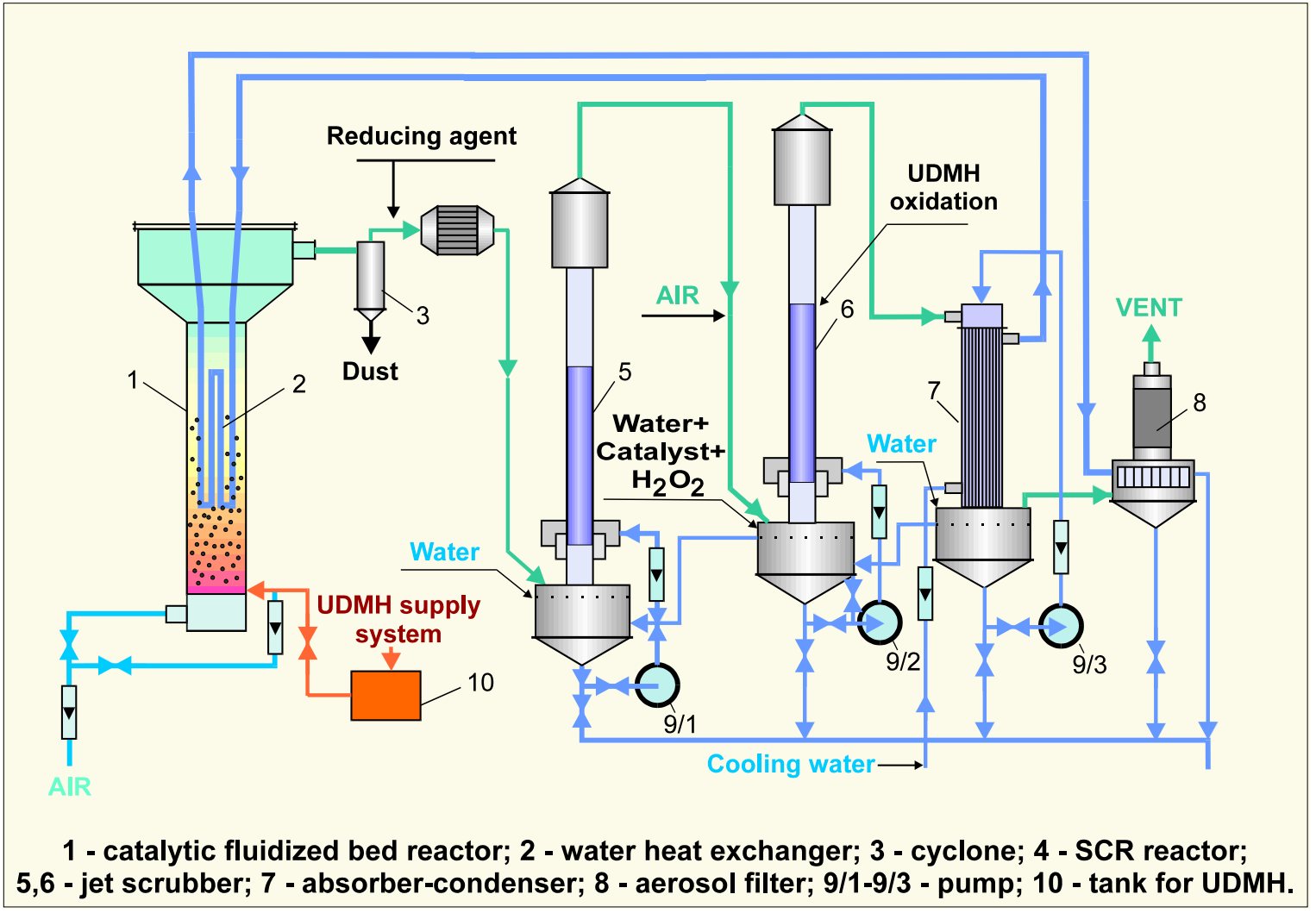


unsymmetrical dimethylhydrazine, UDMH, technical name - heptyl

Method

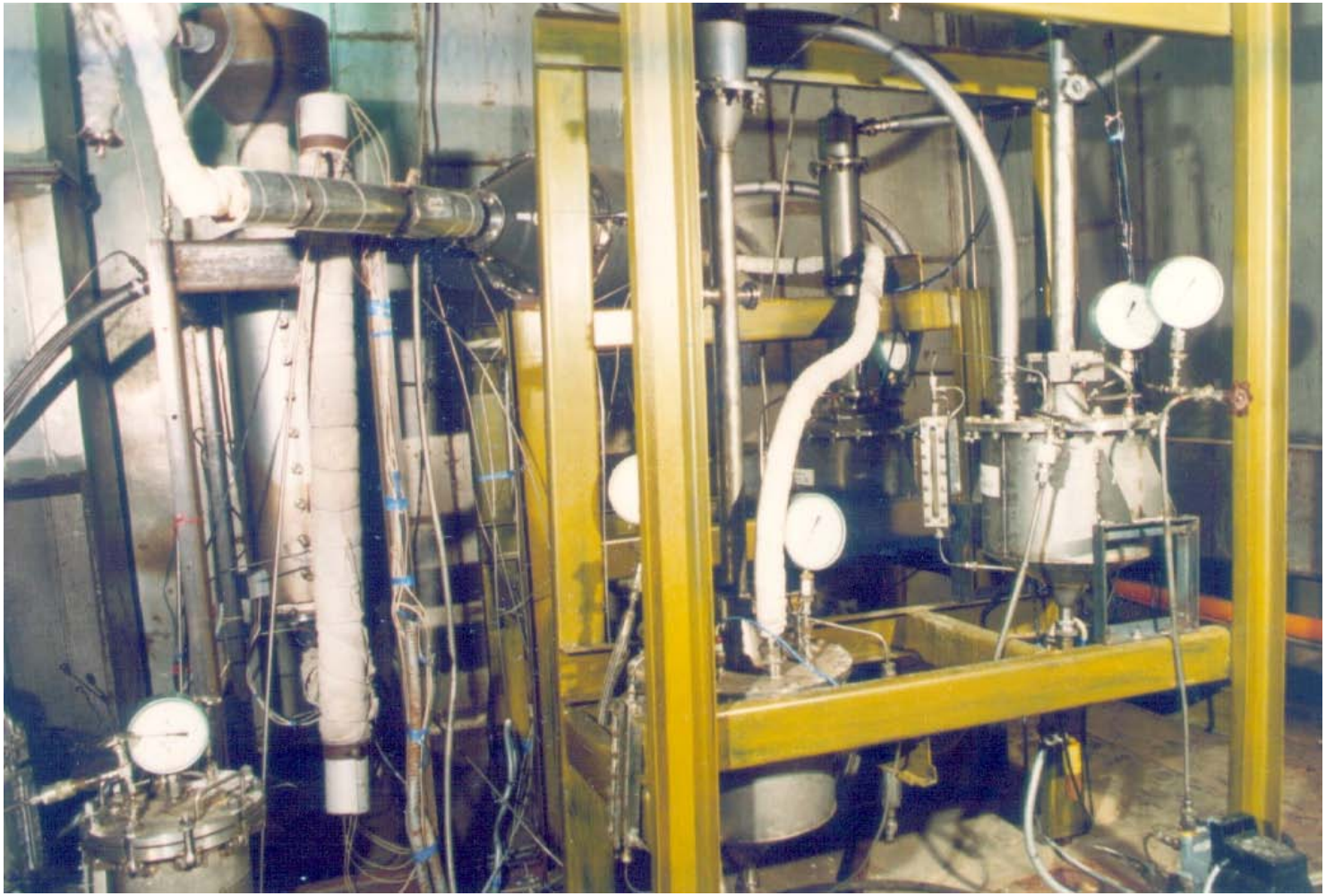
Total catalytic oxidation of UDMH by air in a fluidized bed reactor

Schematics of a Pilot Plant for Catalytic Utilization of UDMH



1 - catalytic fluidized bed reactor; 2 - water heat exchanger; 3 - cyclone; 4 - SCR reactor; 5,6 - jet scrubber; 7 - absorber-condenser; 8 - aerosol filter; 9/1-9/3 - pump; 10 - tank for UDMH.

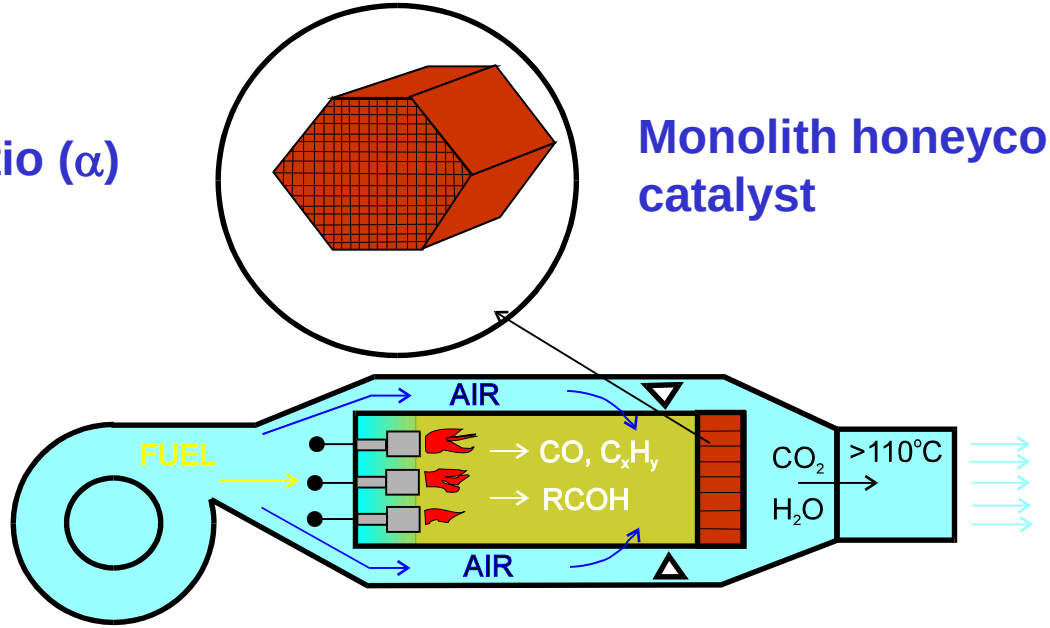
Photograph of the Pilot Plant for UDMH Catalytic Fluidized Bed Destruction

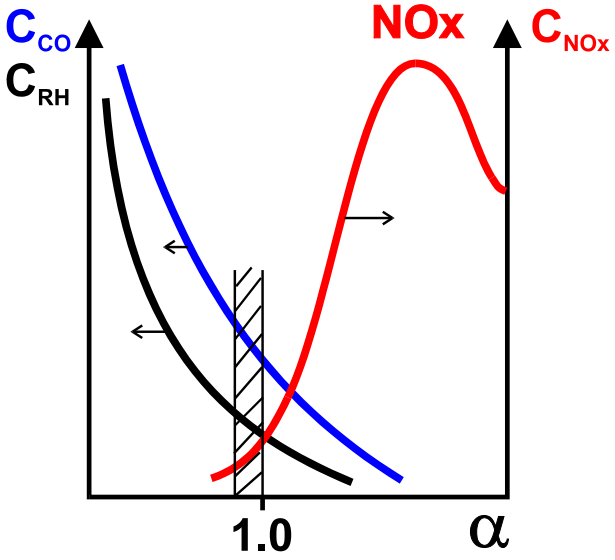


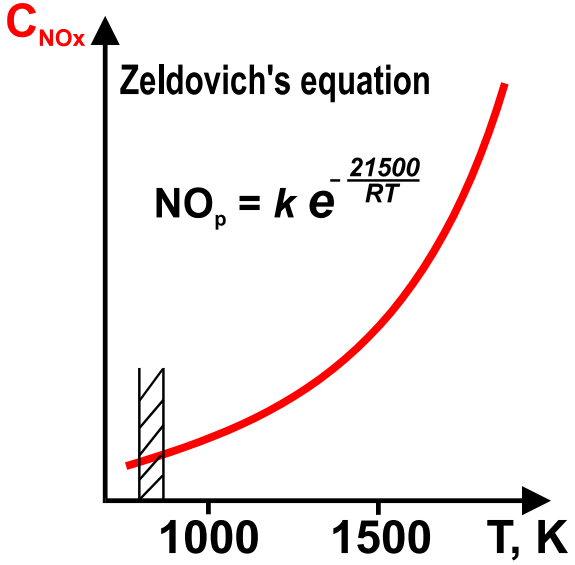
CATALYTIC AIR HEATER
TWO-STAGE COMBUSTION

Oxygen / Fuel ratio (α) at first stage ≤ 1

Monolith honeycomb catalyst







TWO STAGE COMBUSTION

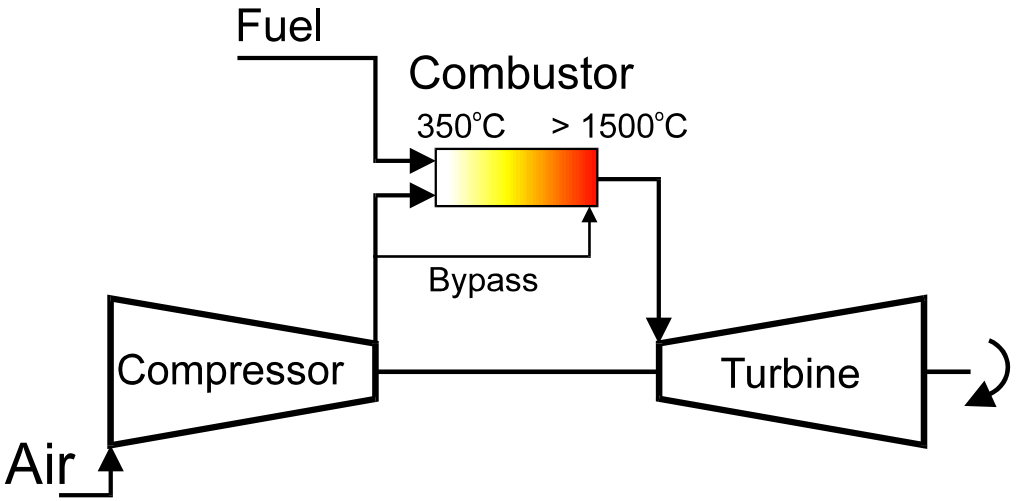
Catalytic cartridges

Two-stage catalytic heat generators has been successfully used for greenhouse heating at farm “Priobskoe” near Novosibirsk, Russia during the last three years

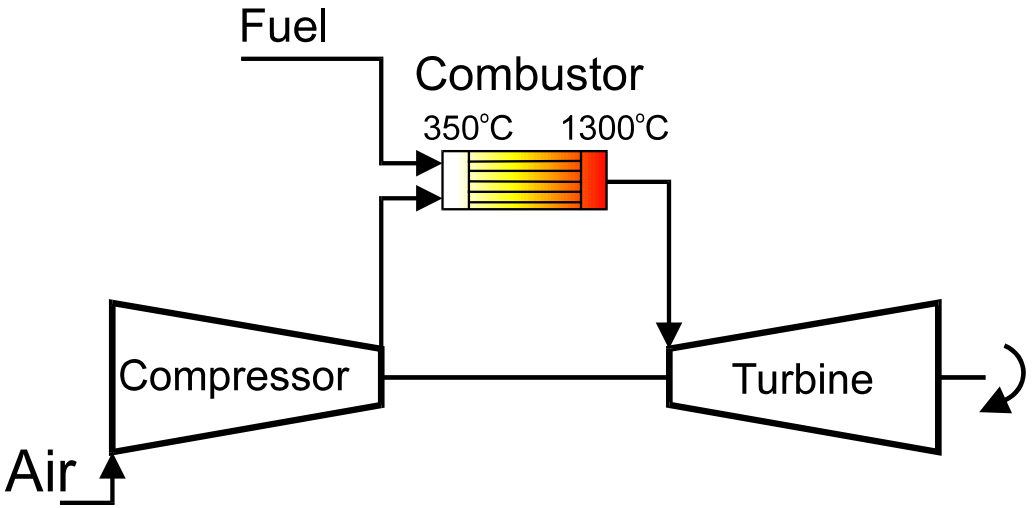
Catalytic gas turbines is a new approach in environmentally clean power production

The use of a catalytic burner in a gas turbine allows:

- reduction of combustion temperature
- stabilization of combustion of lean mixtures
- reduction of NO_x, CO and HC emissions



Conventional gas turbine



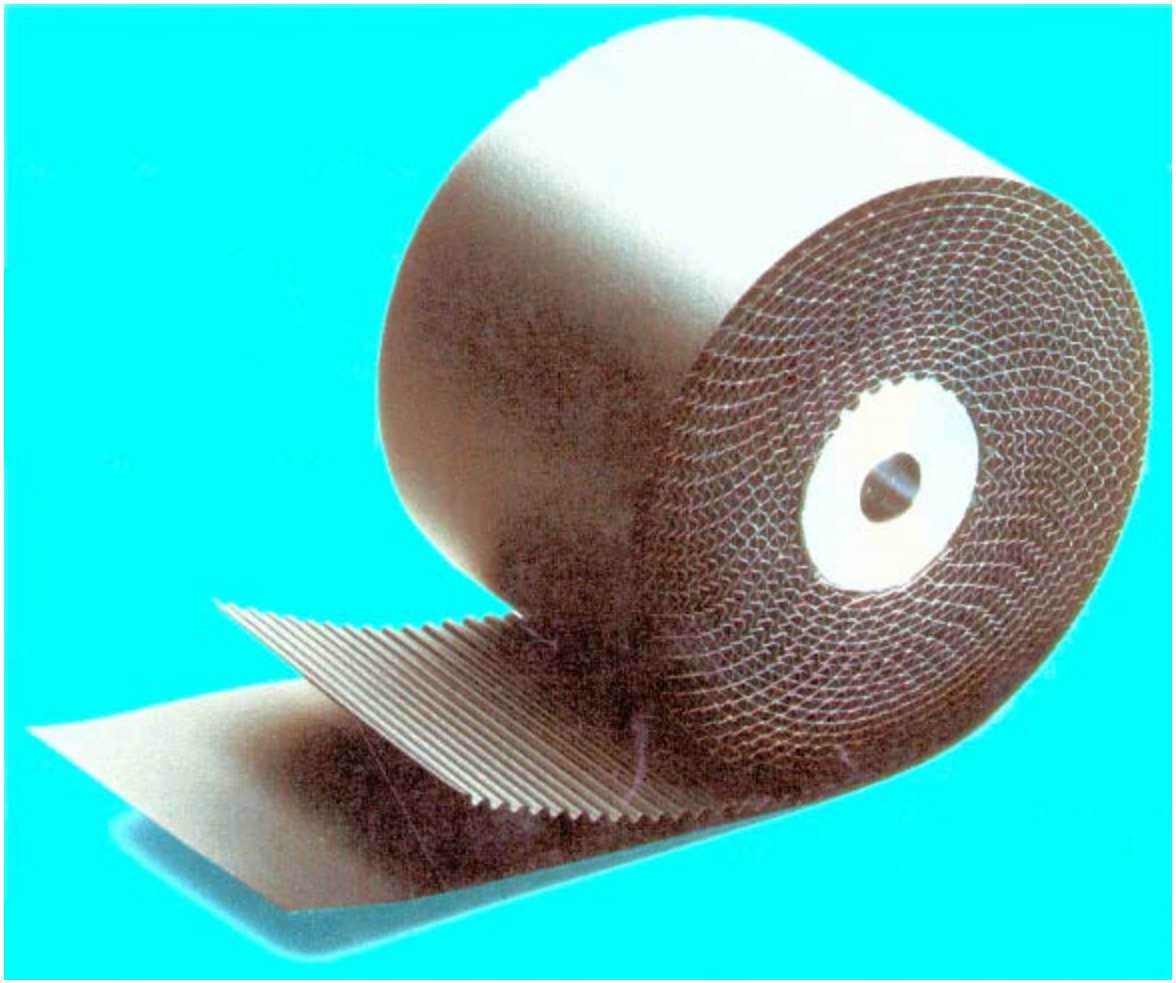
Gas turbine with catalytic combustor

Catalytica combustion Systems, Inc.
www.energysolutionscenter.org/DistGen/AppGuide/DataFiles/Xonon.pdf

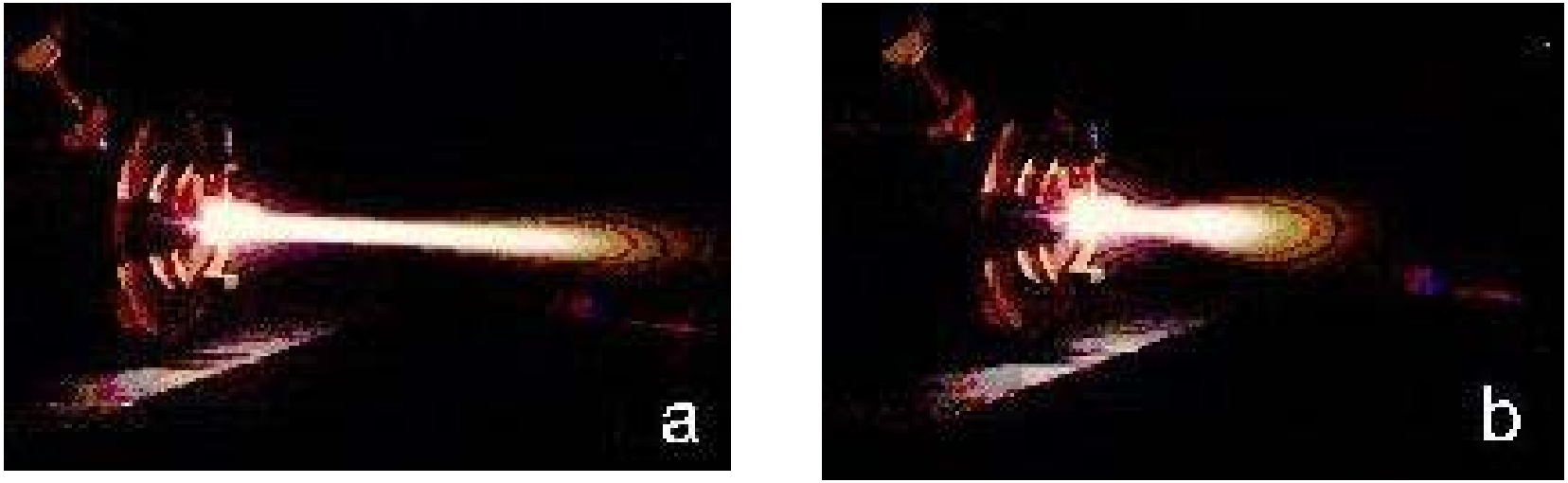
Requirements to catalysts for gas turbines

- high thermal stability (900-1000^{o}C)
- resistance to thermal shocks
- high mechanical strength - P=10 atm, velocity 40 m/s
- pressure drop less than 3%.

METAL MONOLITHIC SUPPORT



Plasma spray coating of catalyst on metal foil



Laminar (a) and turbulent (b) plasma jet outflow.

Micrograph of cross section view of Al_2O_3 plasma sprayed on metal surface

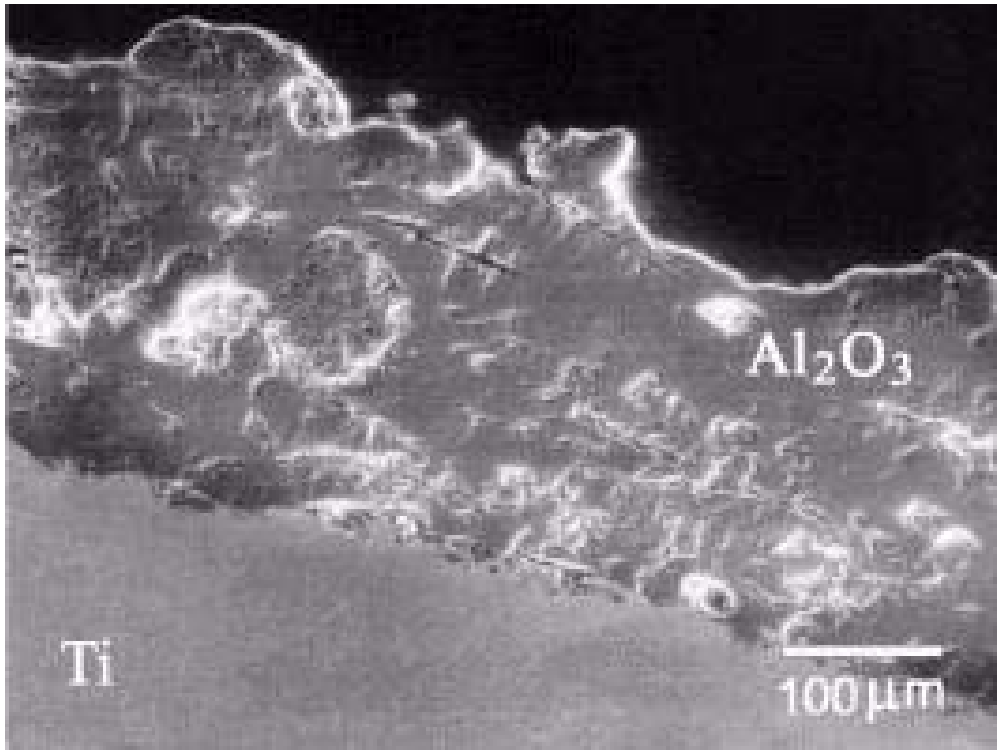
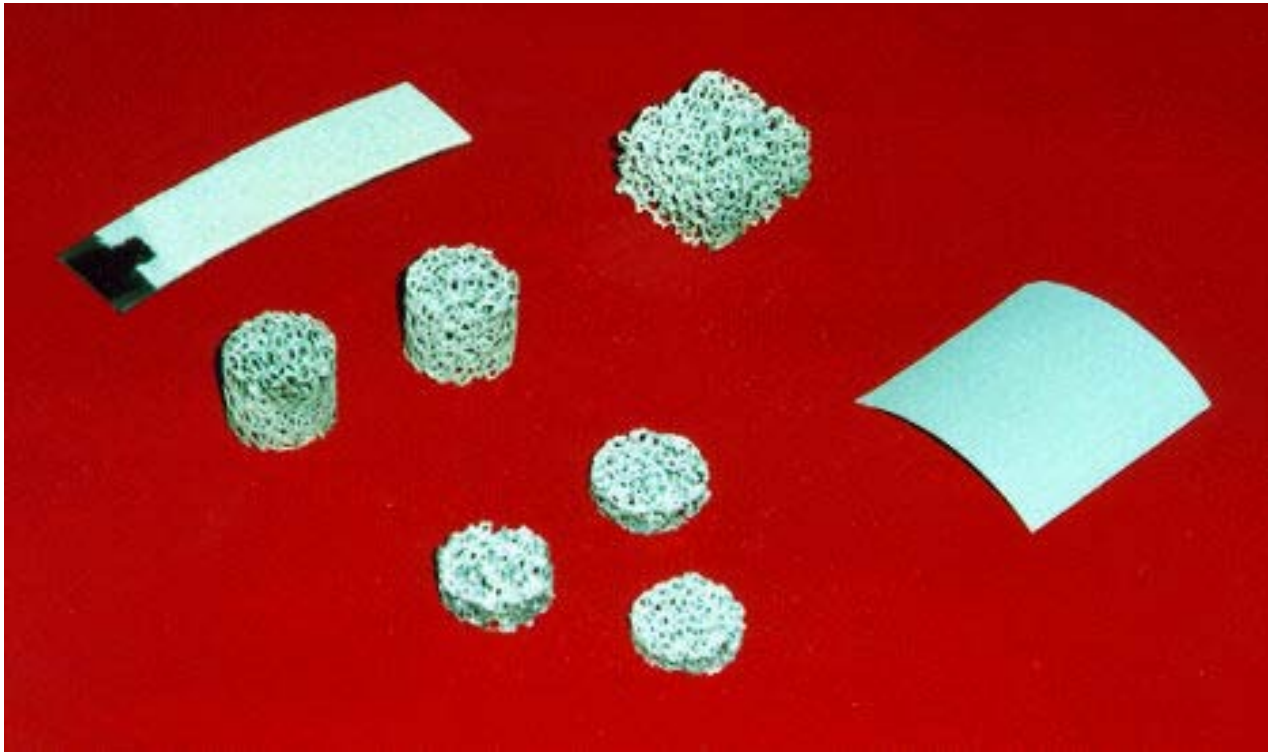
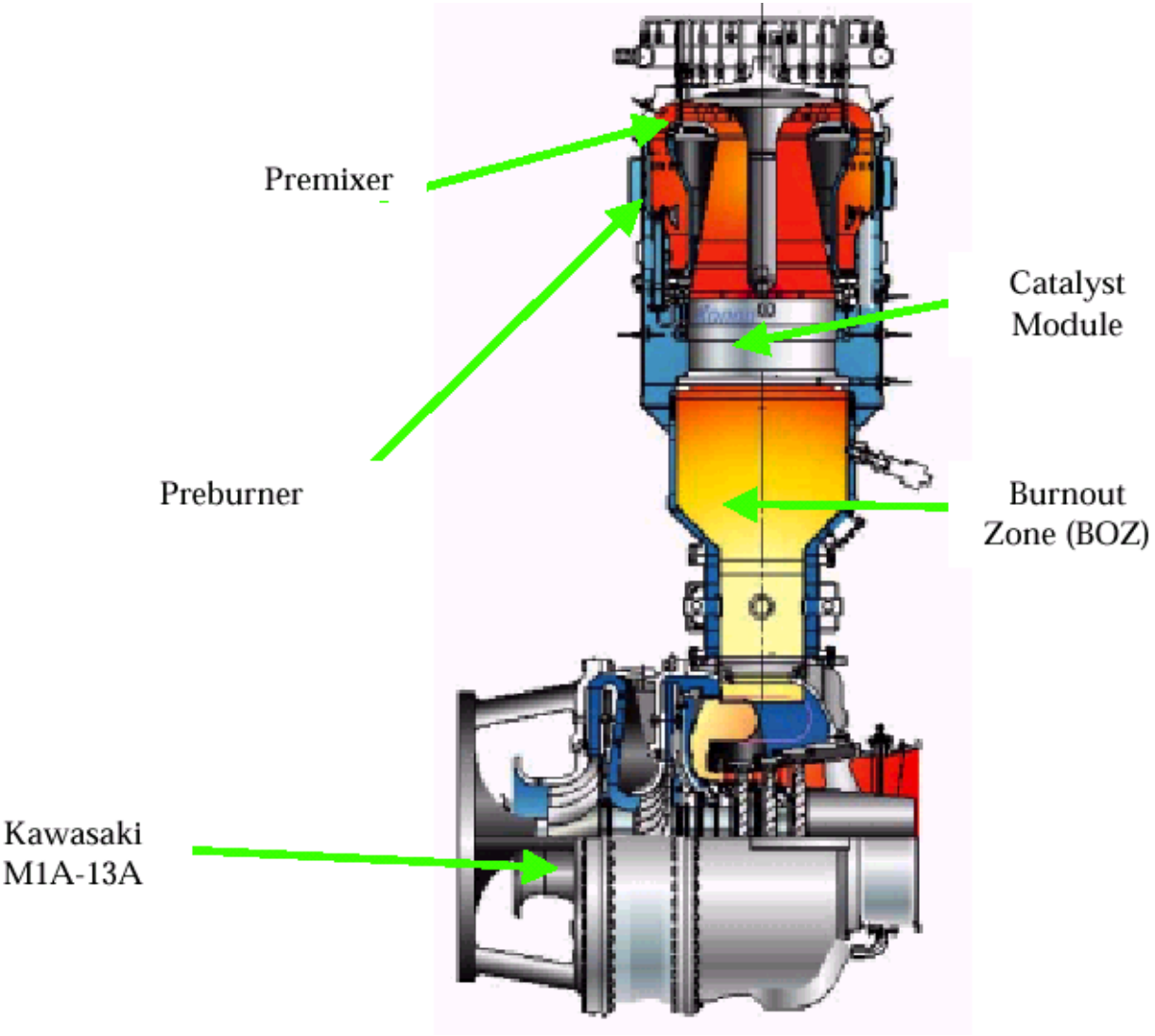


Photo of metal samples with plasma sprayed Al_2O_3

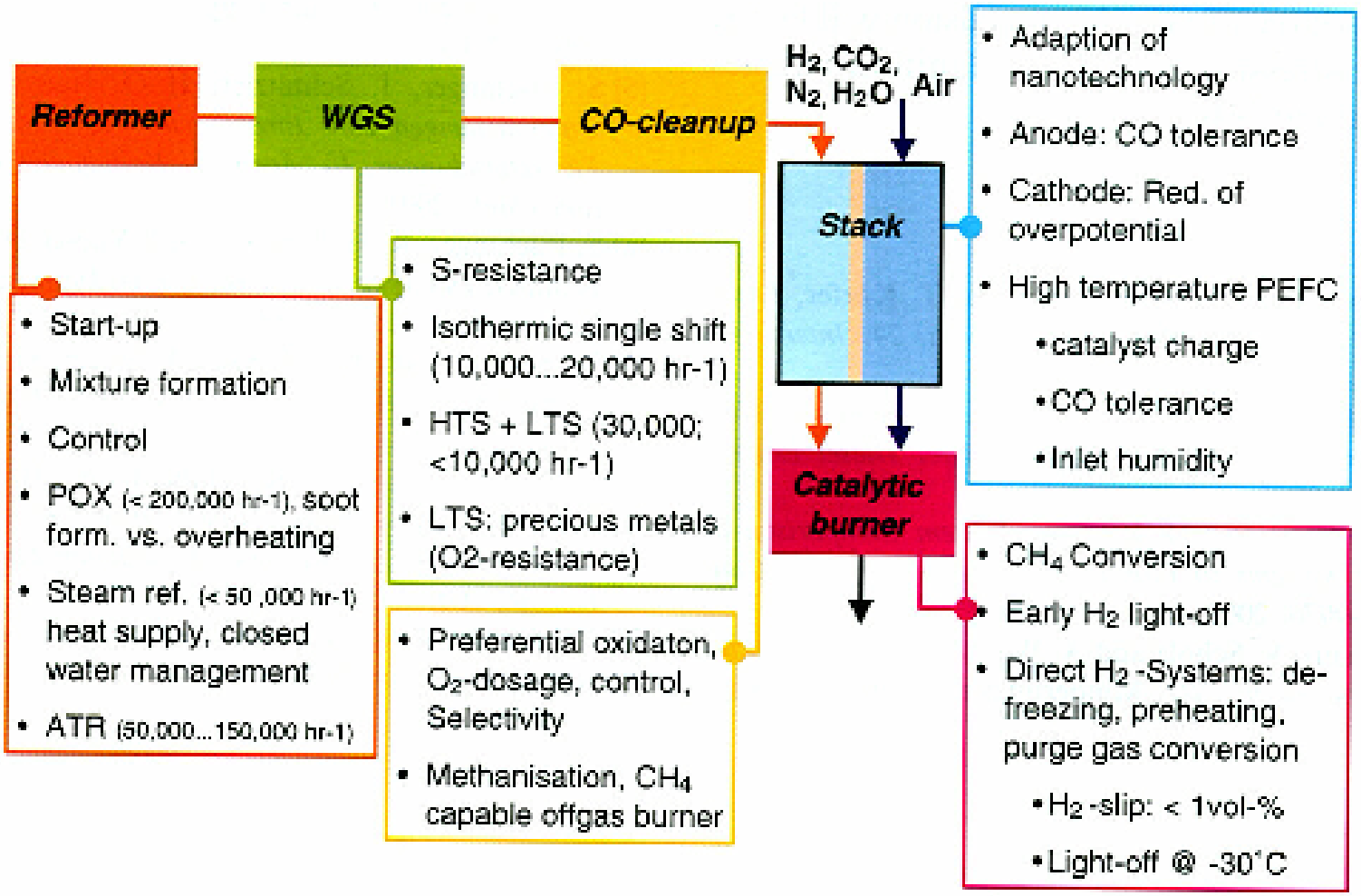


METAL MONOLITH CATALYTIC BURNER

Xonon® Catalytic Combustion System installed on Kawasaki M1A-13A



Catalyst application in fuel cell systems: development focus



Main areas of catalysis application for fuel cell technology

1. Hydrogen production from natural gas and other fuels

2. Catalysis of electrochemical reactions in fuel cell electrodes

Methods of syn-gas production from methane

1. Steam methane reforming

$$CH_4 + H_2O = CO + 3\ H_2 \text{ - } 206\ kJ/mole$$

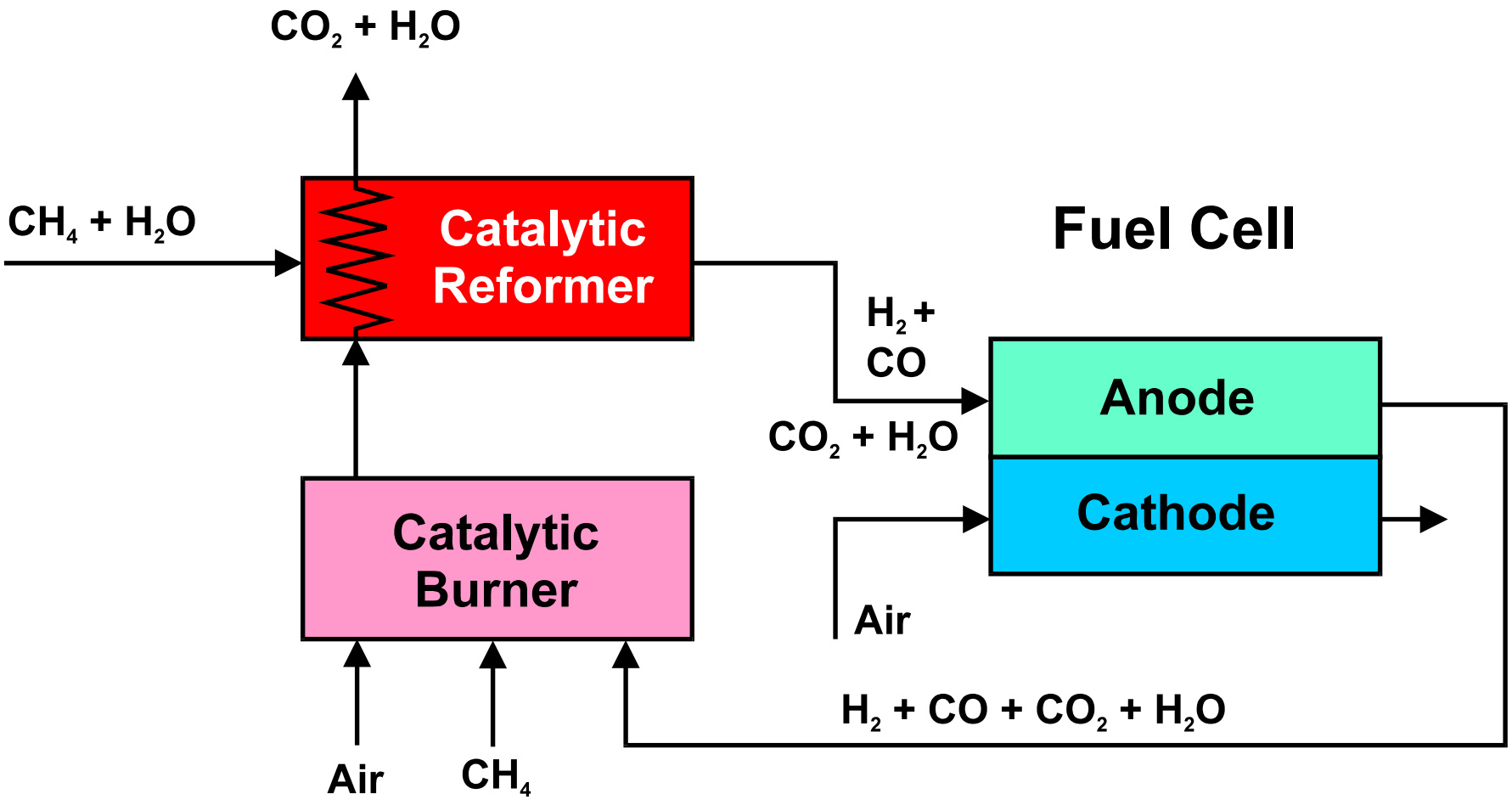
2. Dry methane reforming

$$CH_4 + CO_2 = 2\ CO + 2\ H_2 \text{ - } 247\ kJ/mole$$

3. Catalytic partial oxidation

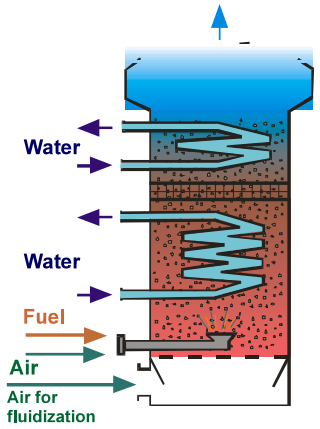
$$CH_4 + 1/2\ O_2 = CO + 2\ H_2 + 36\ kJ/mole$$

Schematic diagram of the process

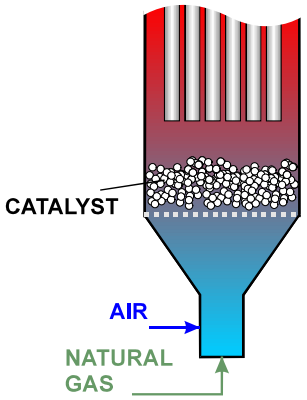


TYPES OF CATALYTIC BURNERS

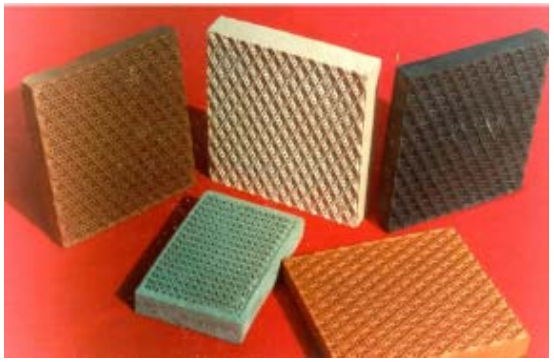
1. Fluidized bed (CHG)



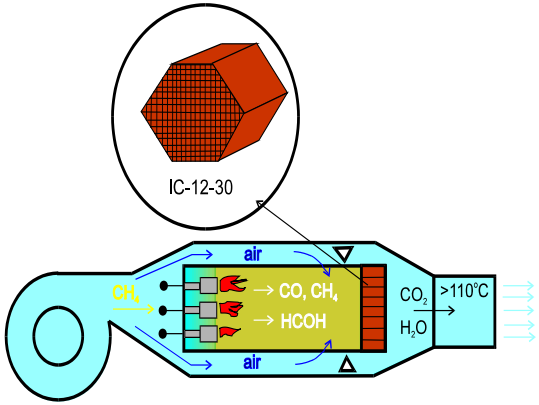
2. Fixed bed



3. Ceramic monolith honeycomb catalysts



4. Two stage combustion

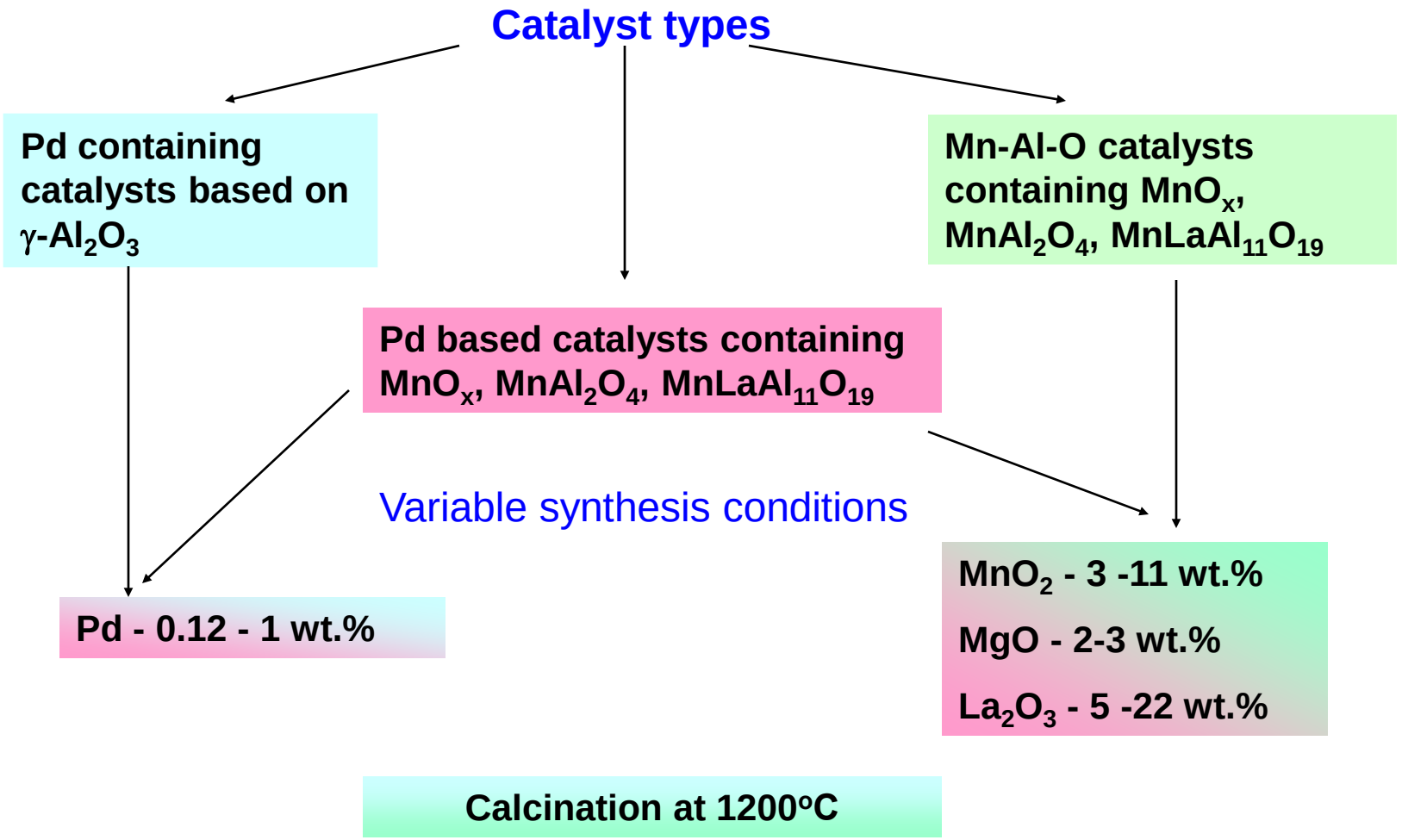


5. Foam material catalysts

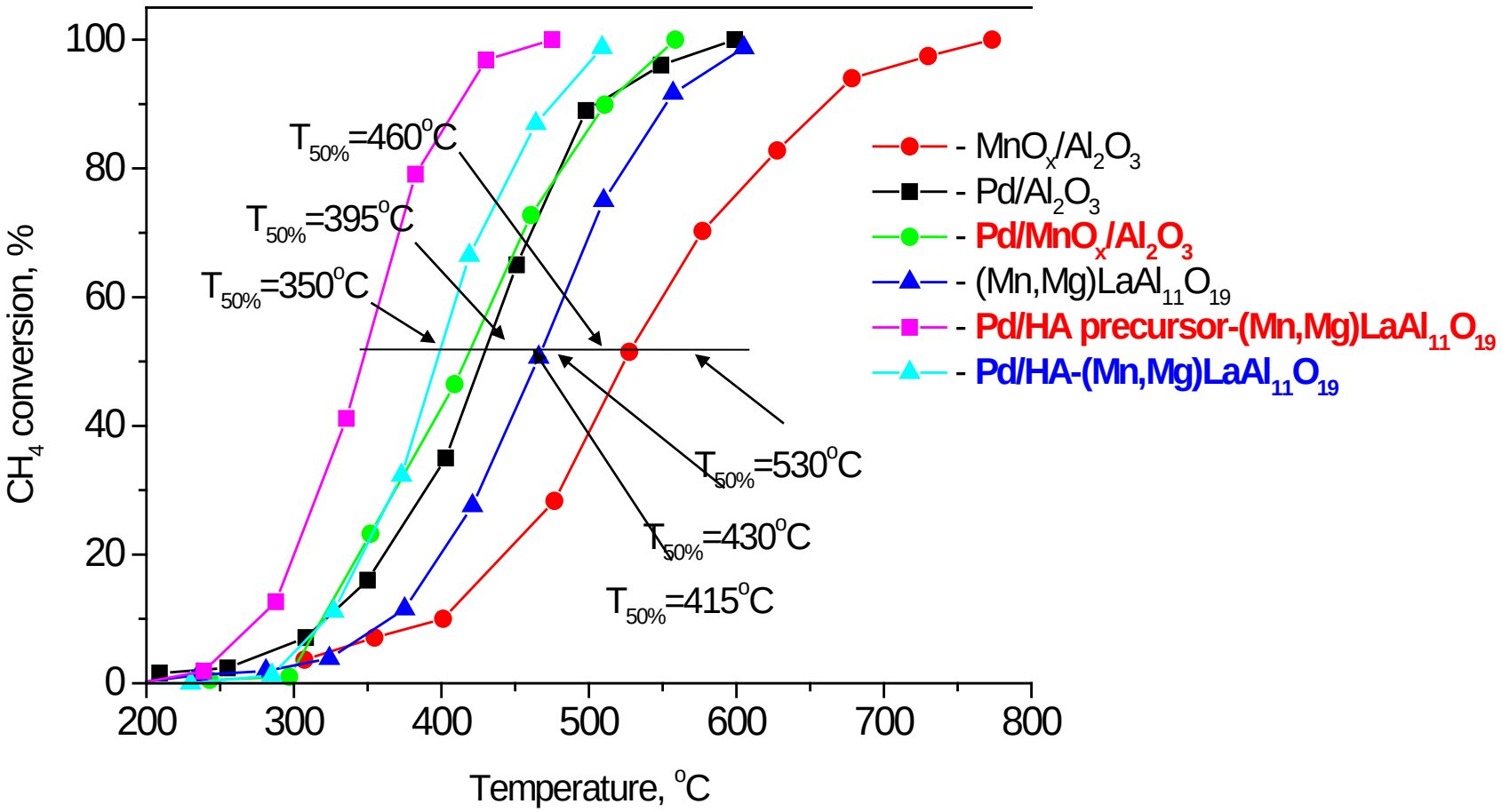
(diameter - 300 mm)

Synthesis of catalysts for combustion of HC fuels.

Systematic variation of synthesis conditions



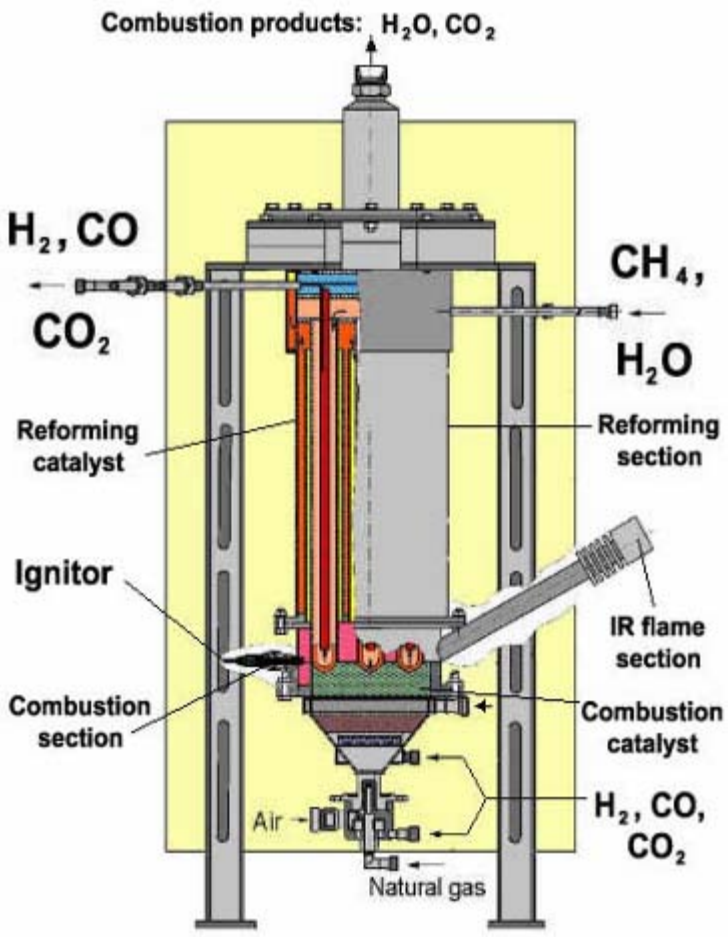
Synergetic effect of Pd and oxide manganese compounds: MnO_x, $MnAl_2O_4$, $MnLaAl_{11}O_{19}$

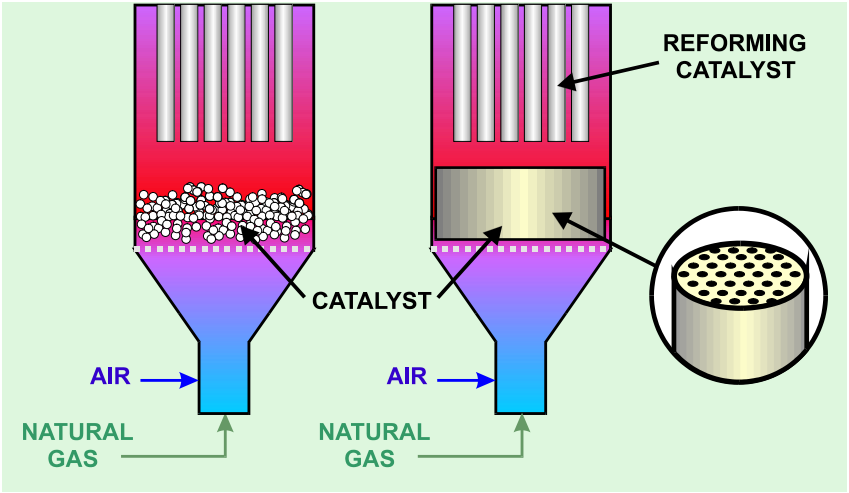


$Pd/MnO_x/\gamma\text{-}Al_2O_3$ ($T_{50\%}$=415°C) ~ $Pd/\gamma\text{-}Al_2O_3$ ($T_{50\%}$=430°C) <

$Pd/HA\text{-}(Mg,Mn)LaAl_{11}O_{19}$ ($T_{50\%}$=395°C) < Pd/HA precursor-$(Mn,Mg)LaAl_{11}O_{19}$ ($T_{50\%}$=350°C)

Catalytic burners for reformers of fuel cell energy installations





Two types of catalysts