Process Intensification Through Miniaturization

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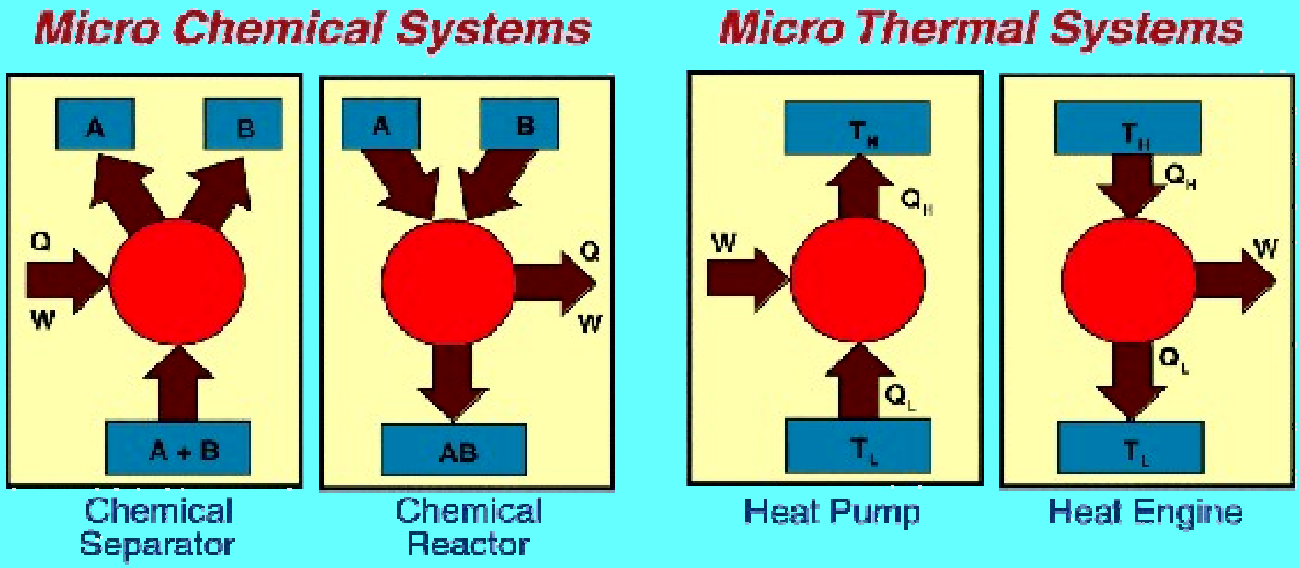
Micro Chemical and Thermal Systems in the 21st Century

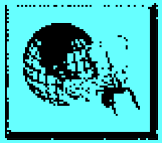
- Process Intensification
- Evidence for Success
- Progress Toward the Future
- MICRO-CATS™ in the 21st Century

Micro Chemical and Thermal Systems

- Develop microcomponents that can perform unit operations
- Assemble unit operations into systems

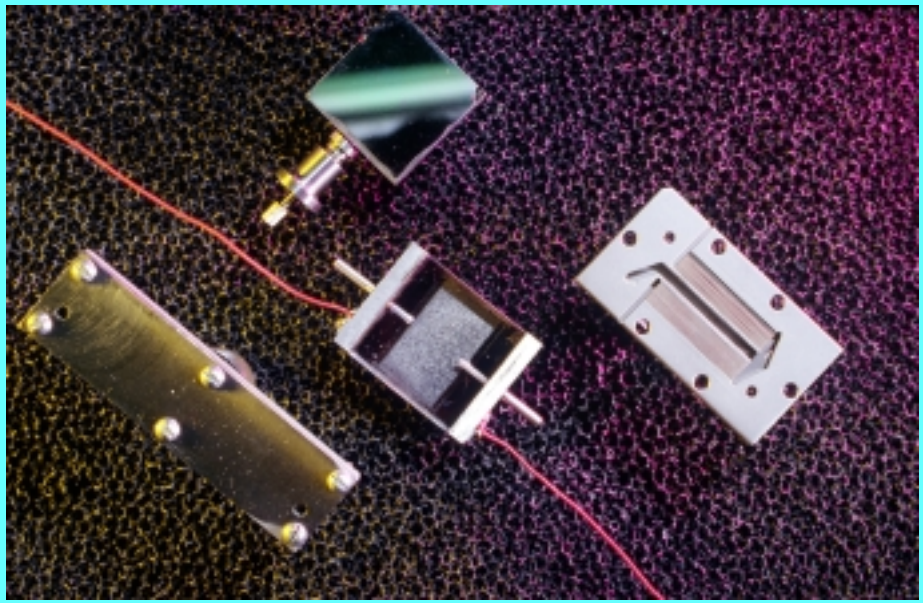


MICRO-CATS™ Applications

	Buildings		Military
	Carbon Management		Space Exploration
	Environmental Restoration		Transportation
	Industrial Chemical Processing	?	What's Next

Process Intensification

Conventional tools



New tools: Micro Chemical and Thermal Systems

Process Intensification

- Primary Fruit of Miniaturization
- Reduction in Resistances to Heat and Mass Transfer
- Orders-of-Magnitude Improvement in Processes
- Compact, Lightweight, Efficient Systems

Why Microtechnology?

- Microscale Advantages
  - Rapid heat/mass transport
  - Nonequilibrium chemical products
  - Surfaces forces
  - High productivity per unit volume (hardware)
- Compact Systems
  - Distributed and mobile applications
  - Energy and chemical conversions at optimum locations
- Economies of Mass Production
- Potential for the Incorporation of Molecular Systems (Nanotechnology)

Impact of Miniaturization

- Heat Exchangers
- Heat Pumps
- Reactors
- Absorbers
- Adsorbers

All chemical and thermal processes plus pumps, valves, compressors, etc.

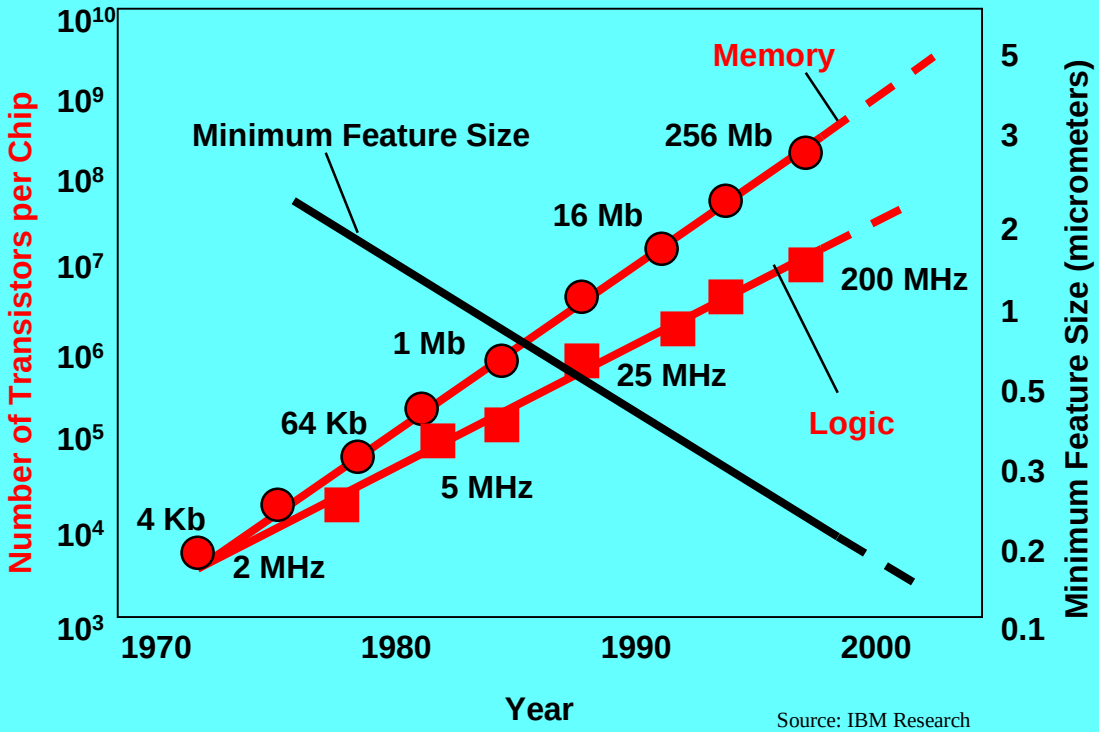
Process Intensification Changes → Revolutionary Changes

- Adjust building thermostat → Clothing that heats and cools
- Internal combustion engines → Fuel cells and other systems
- Transplant some organs → Use artificial organs

Miniaturization in Electronics

- Transistor Invented
- Small Lightweight Portable Radios
- Today - Palm Computers, Cell Phones and More

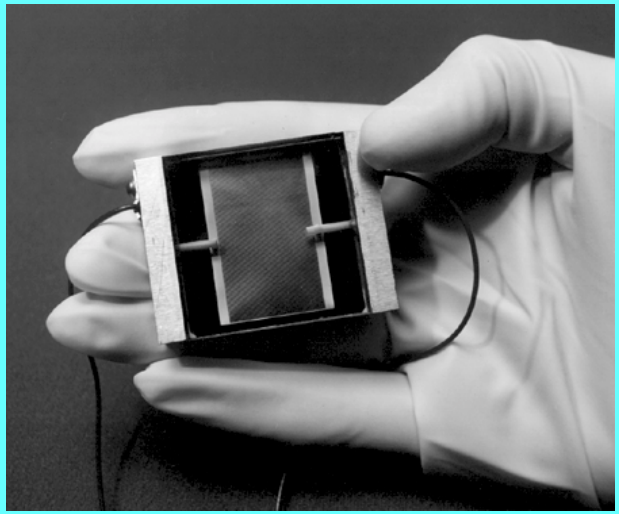
The Power of Miniaturization

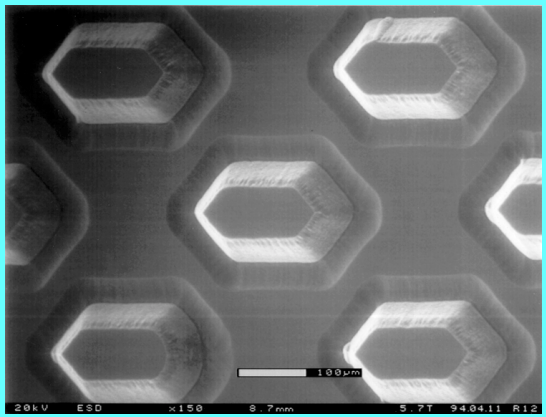


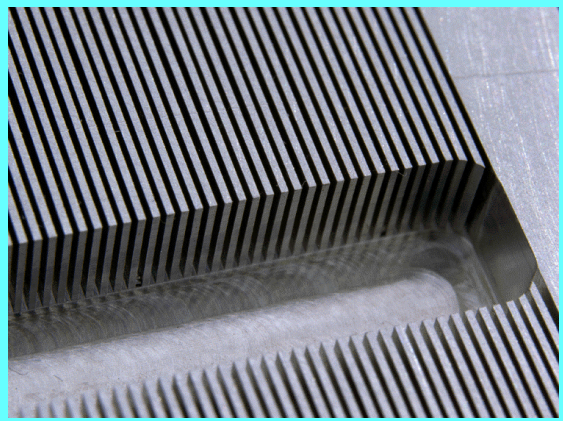
Source: IBM Research

Microchannel Heat Exchangers

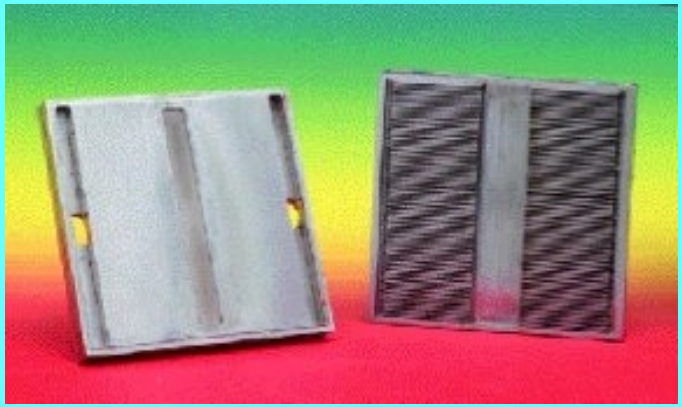
Heat fluxes: 100+ watts/cm^2
Low pressure drops: 1-2 psia
High convective heat transfer coefficients
- Liquid phase: 10,000 - 15,000 watts/m^2-K
- Evaporating phase: 30,000 - 35,000 watts/m^2-K

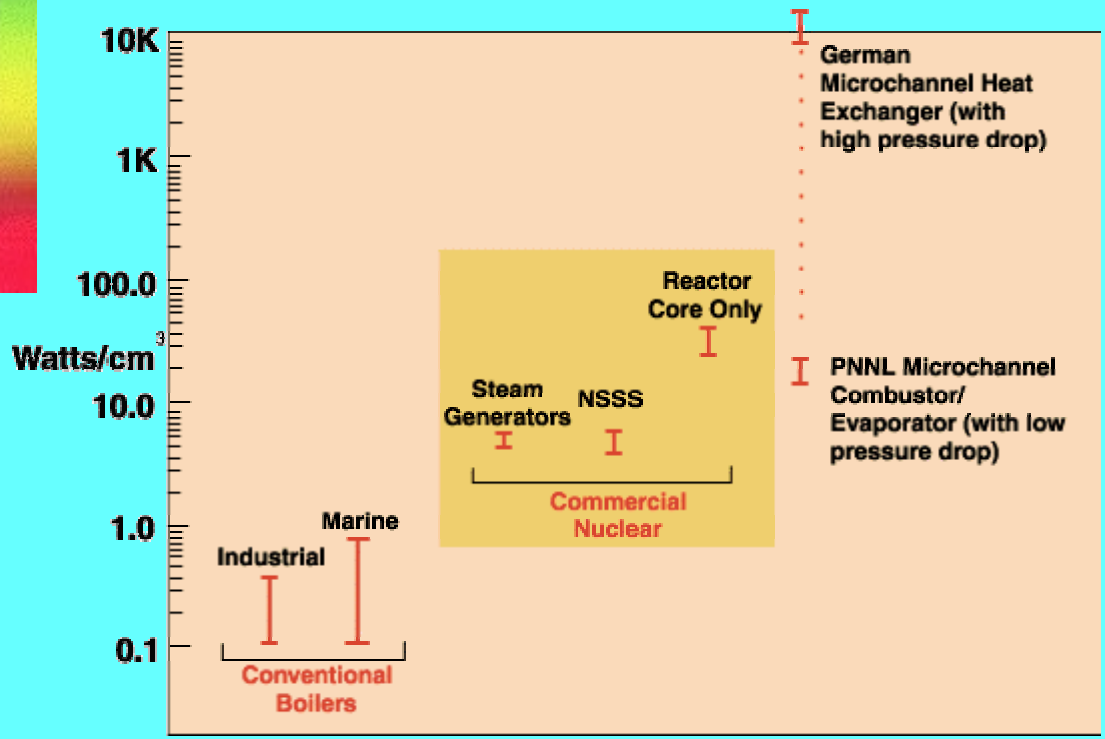




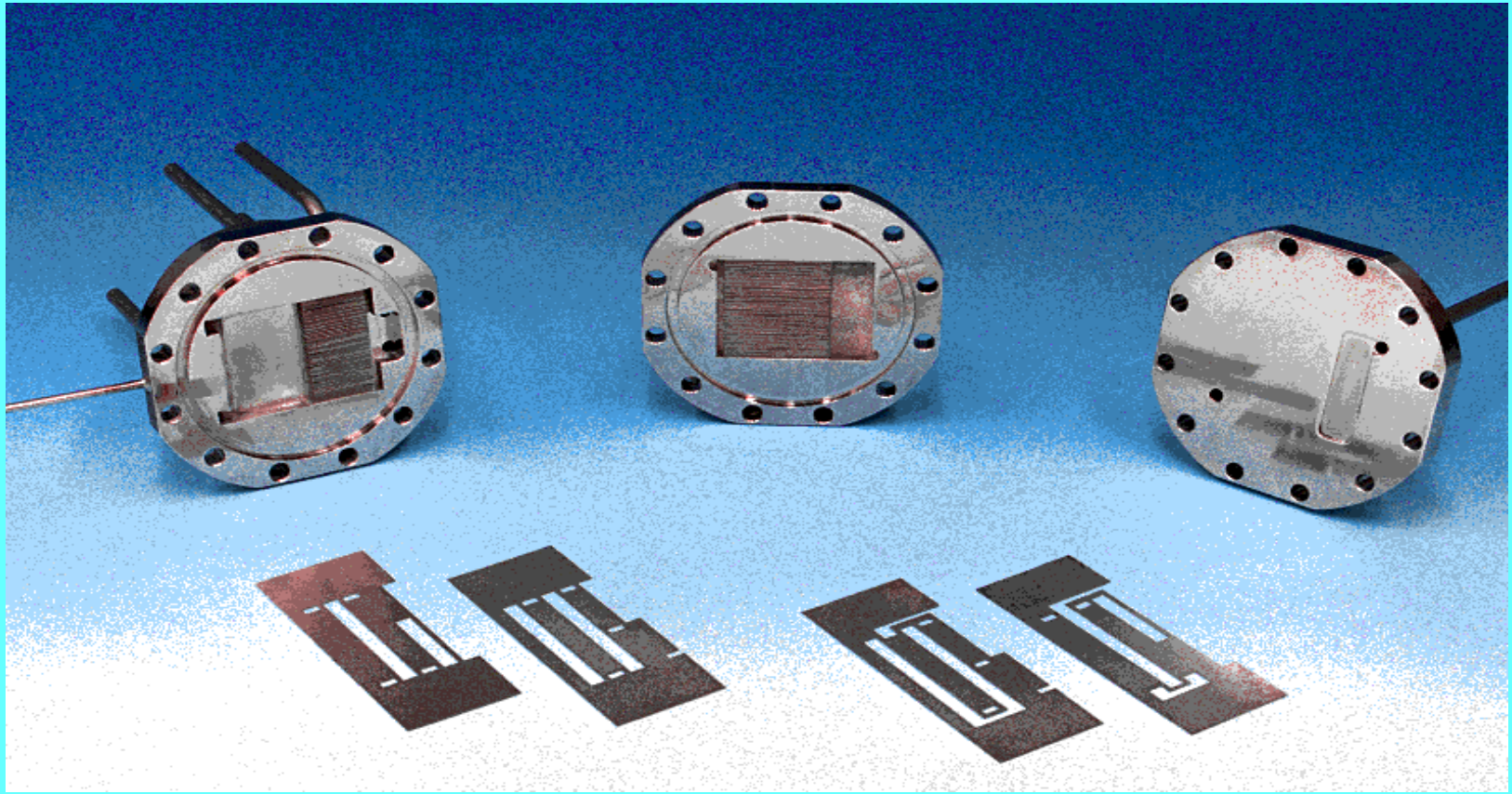


Microchannel Heat Exchangers

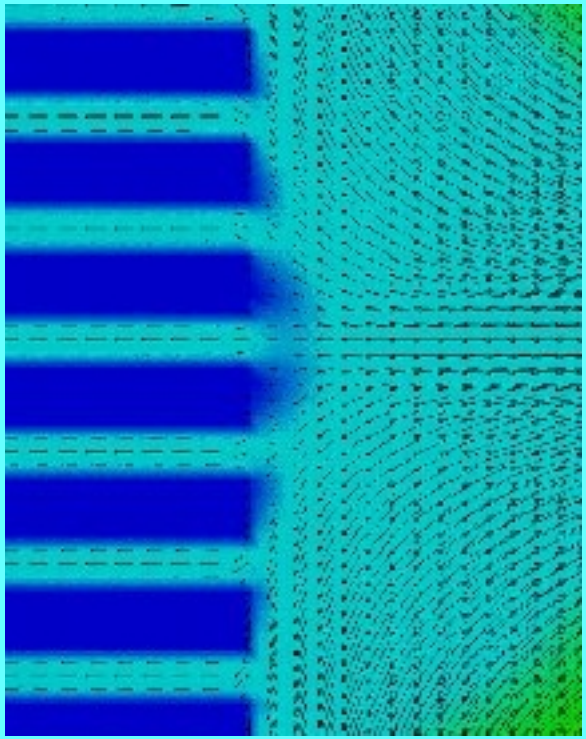


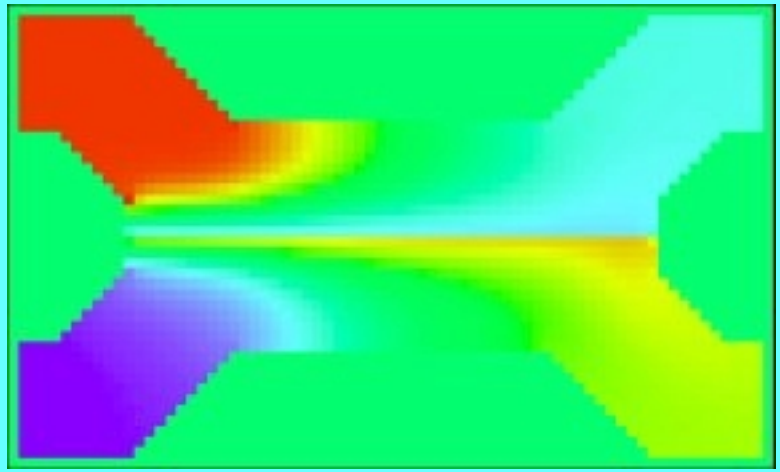


Microchannel POX Reactor Test Unit



Simulation of MICRO-CATS™



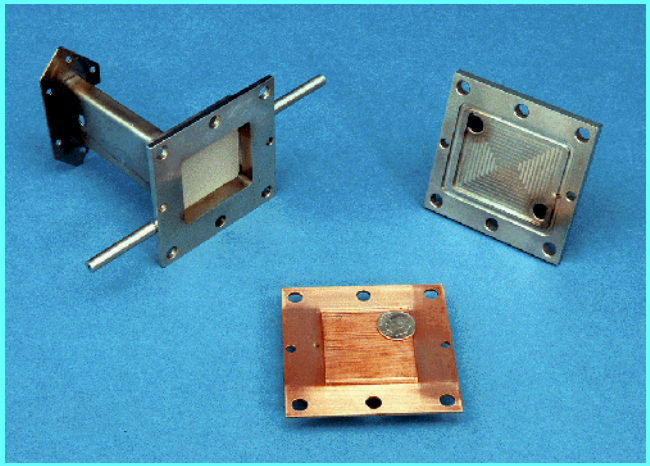


Progress Toward the Future

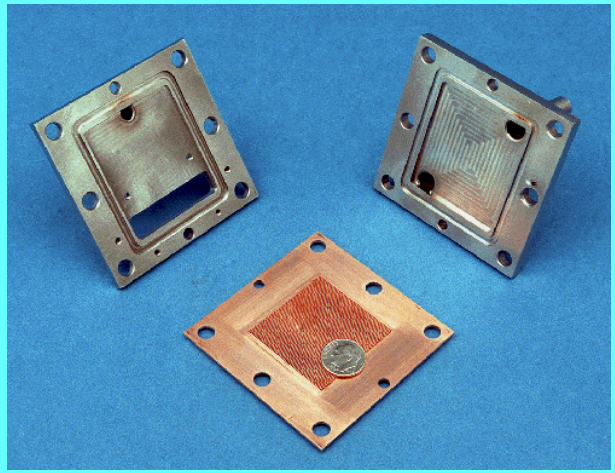
- Man-Portable Cooling
- Automotive Fuel Processing
- In Situ Resource Utilization

Man-Portable Systems

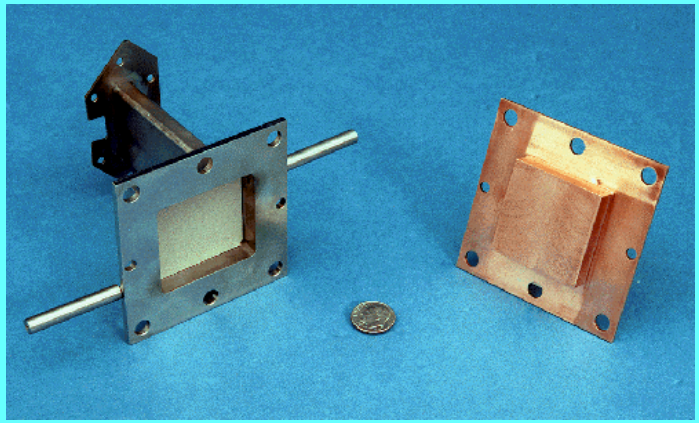
Absorption Heat Pump Components



Absorber

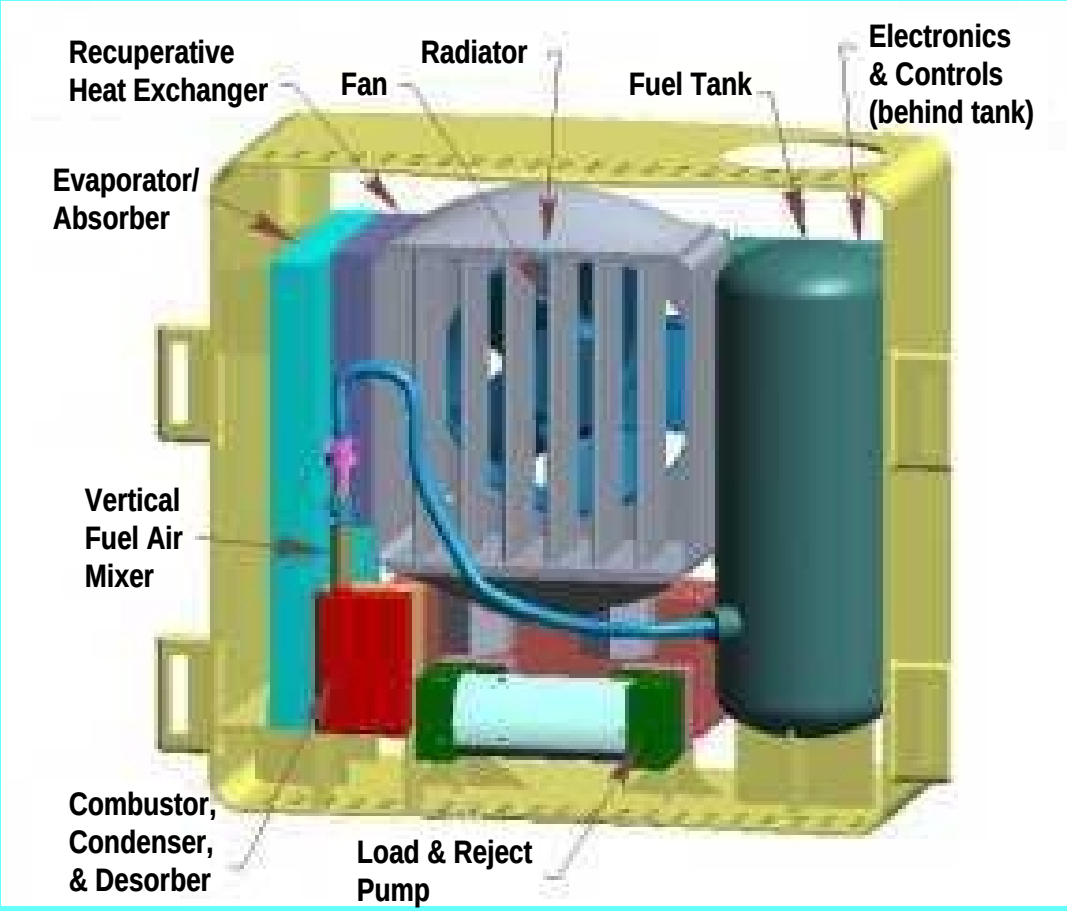


Evaporator Condenser



Desorber

Man-Portable Cooling



Absorption Heat Pump Performance

Cooling load: 360 watt with 46°C ambient temperature

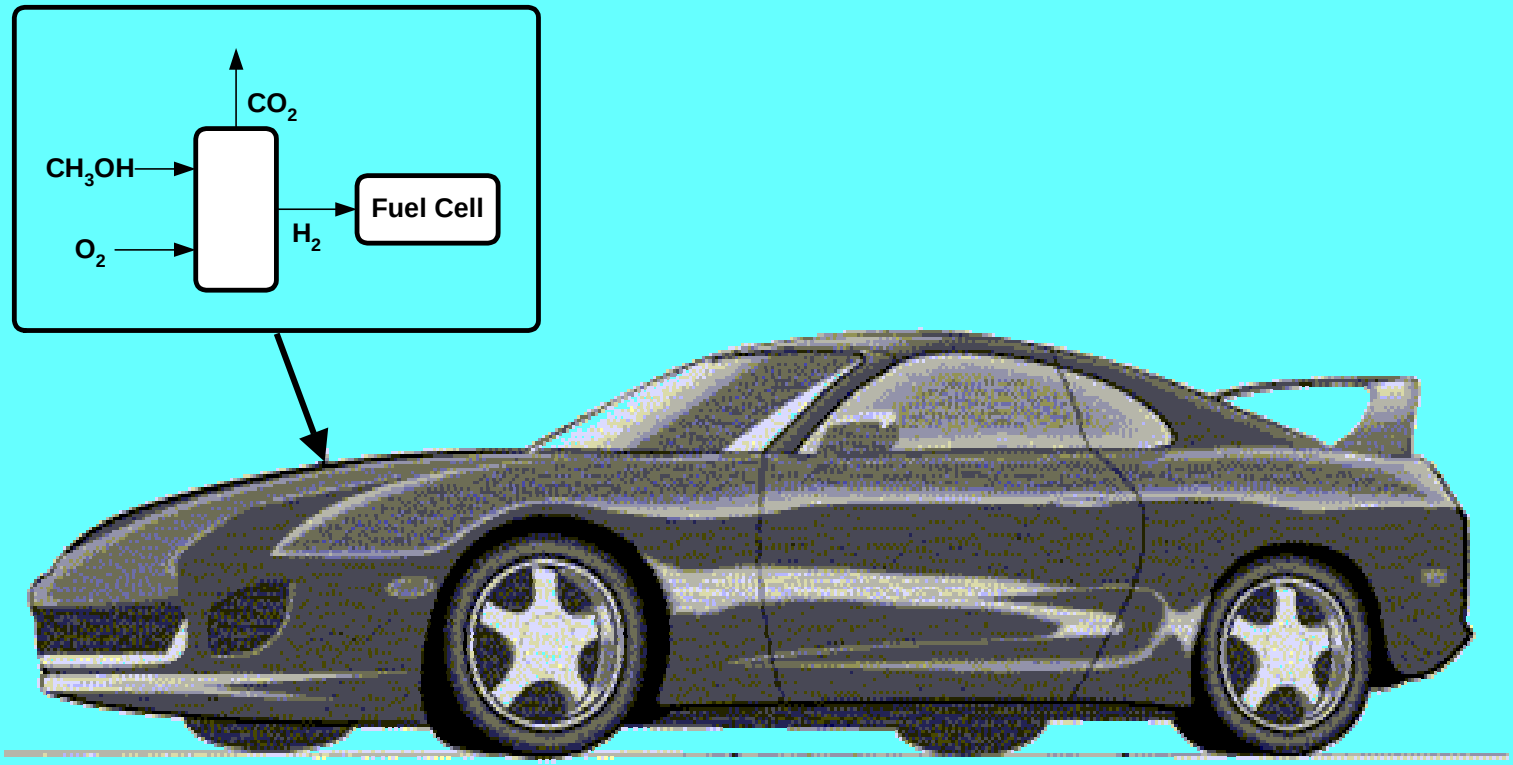
Weight: 5.0 kg

Fuel: liquid hydrocarbons (butane, JP-8, diesel)

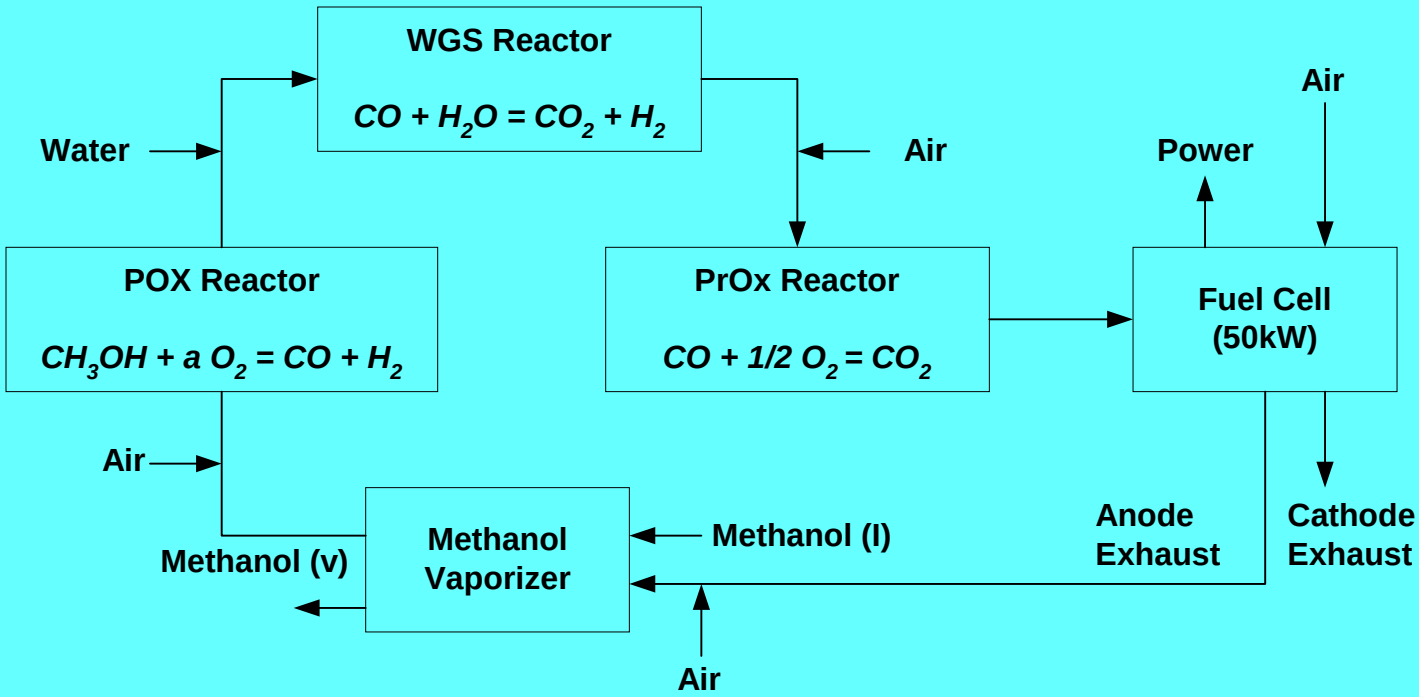
Duration: 8 hours

Orientation: operation is independent of orientation

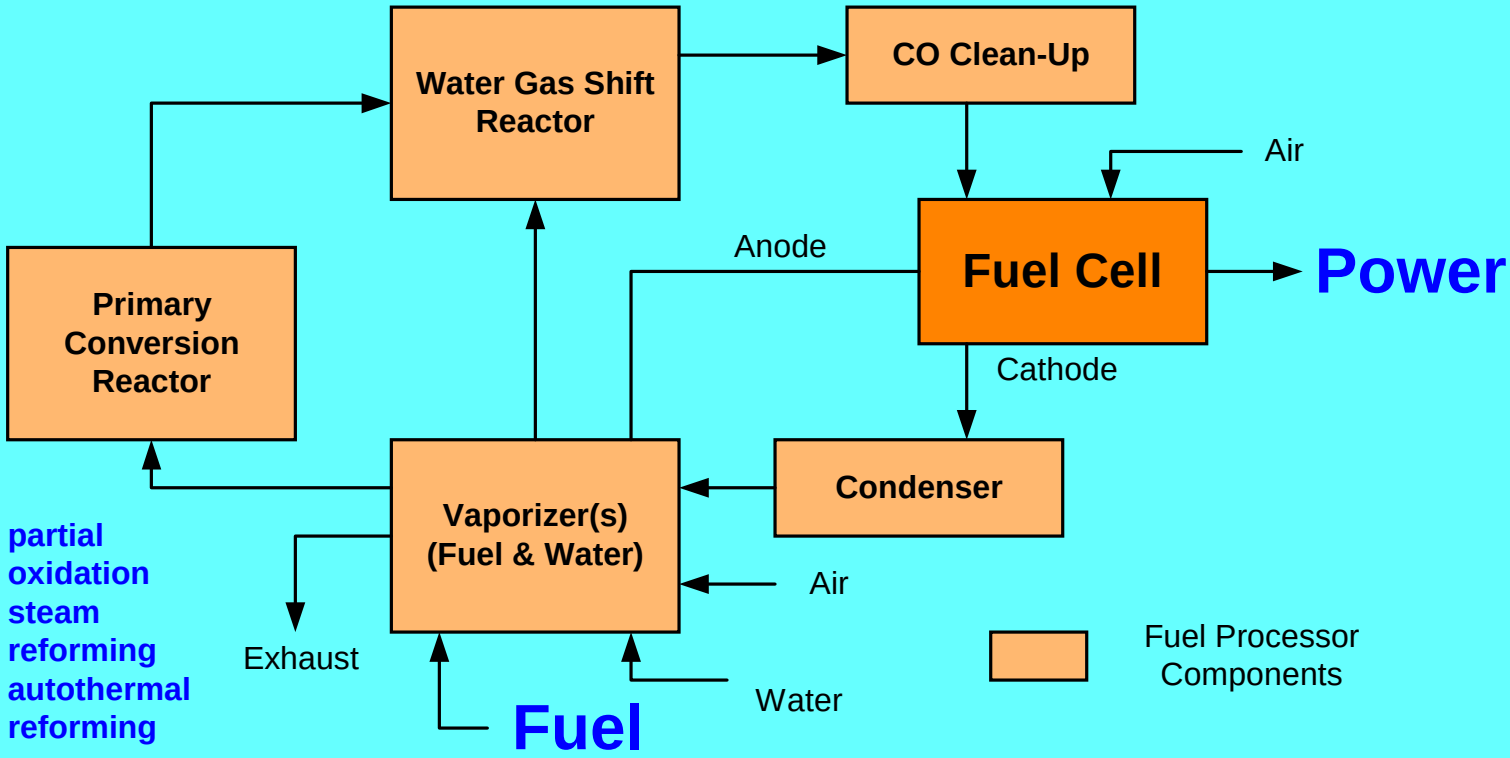
Automotive Systems



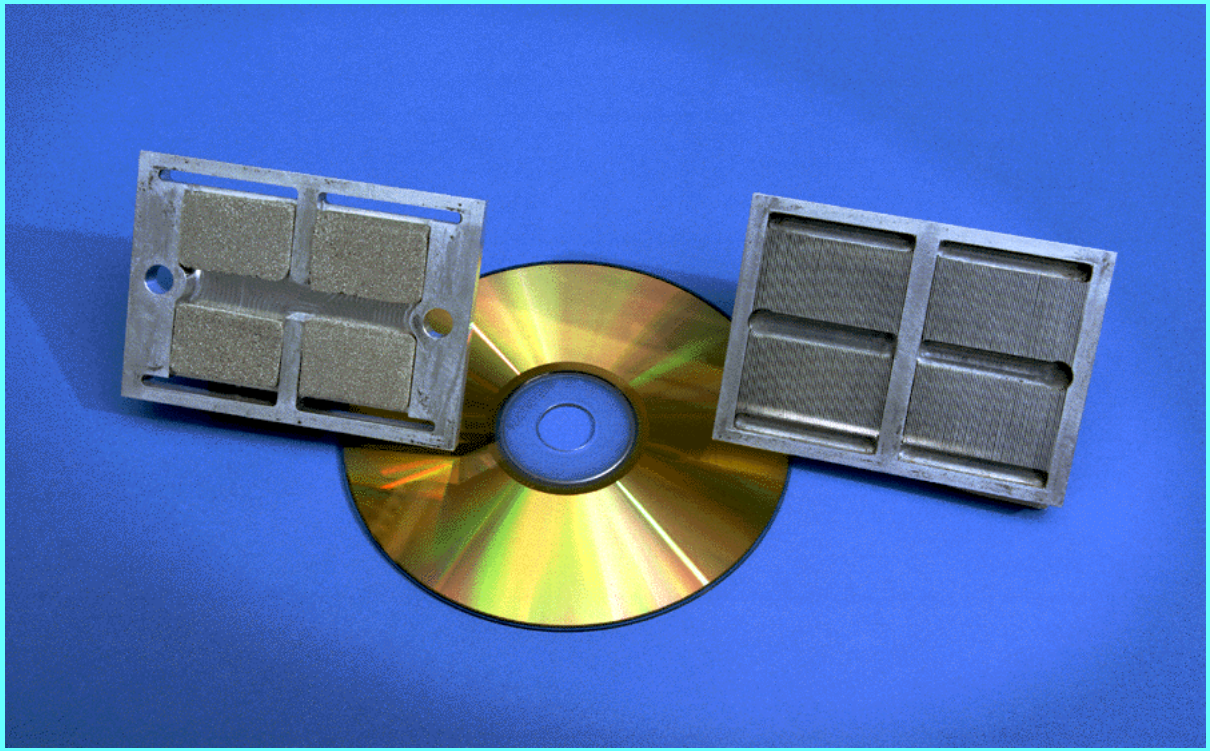
Automotive Fuel Processor Components



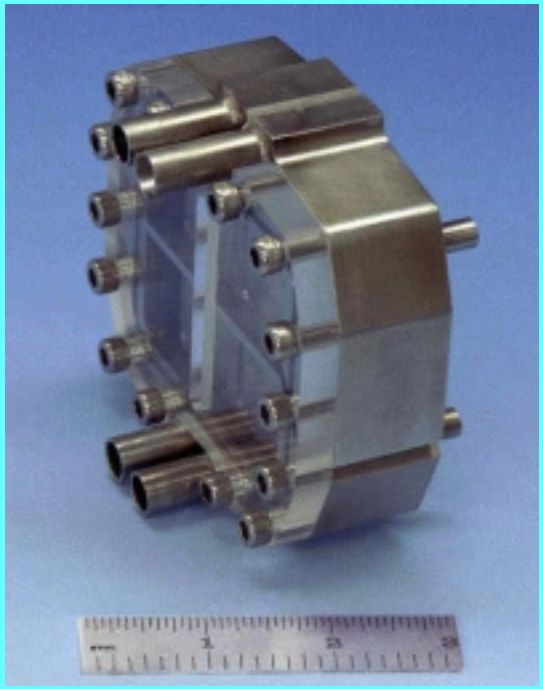
Automotive Fuel Processing



Automotive Fuel Processor Vaporizer

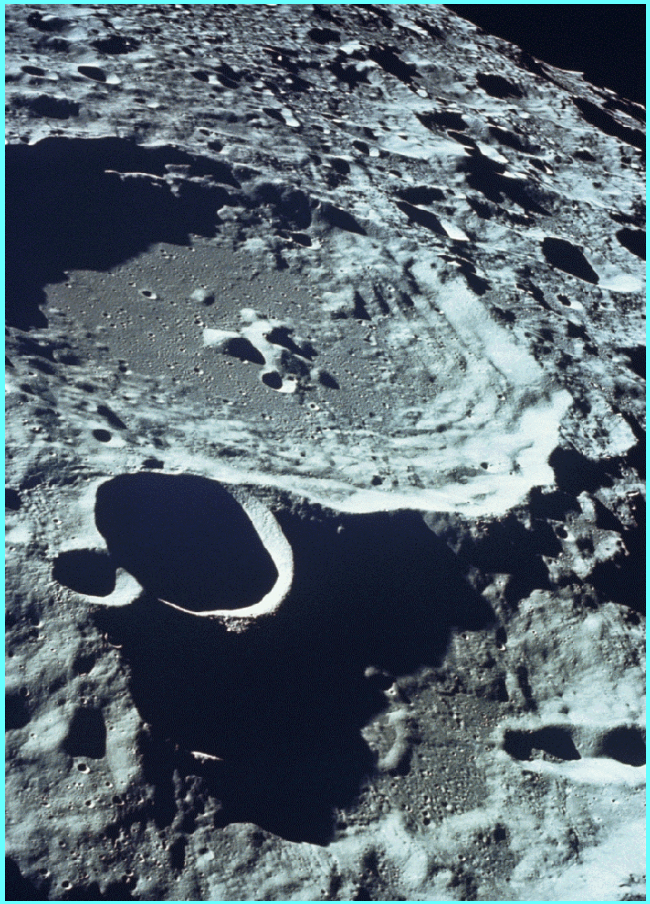


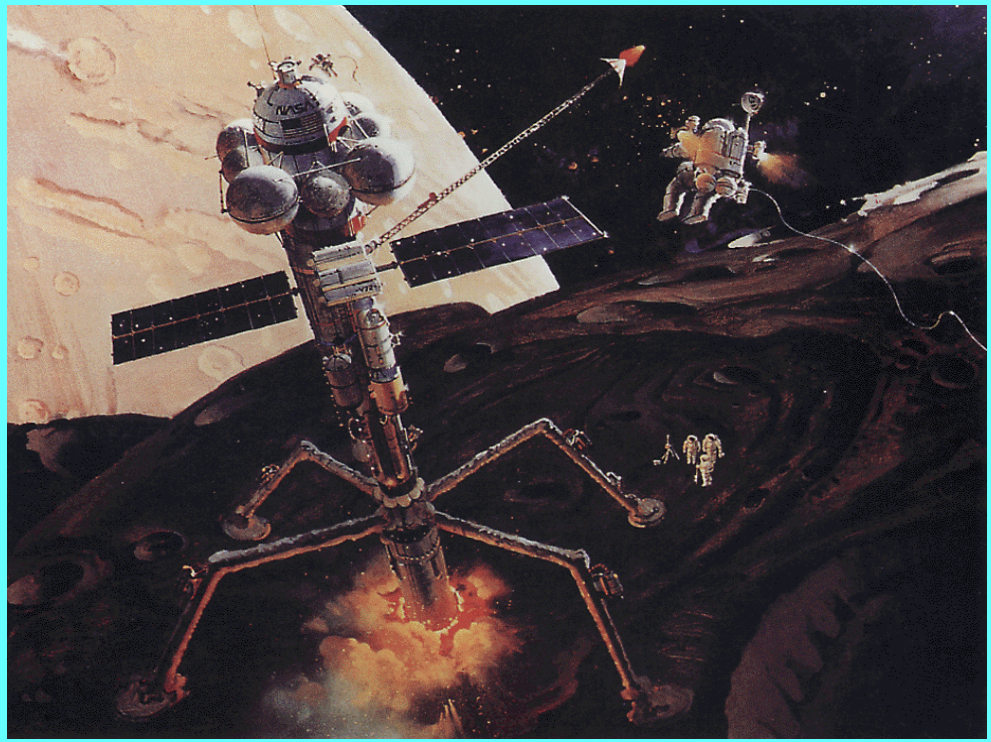
Full-Scale Microchannel Gasoline Vaporizer



Attributes: Four parallel cells of microchannel reactors and four cells of microchannel heat exchangers
Size: 3” by 4” by 1.5”
Capacity: Vaporized gasoline for 50-kW fuel processing system
Implications: Complete fuel processor system = 0.3 ft^3
Fabrication: Laminate process
Pressure drop: $\Delta P < 2$psi through microchannels at 1400 SLPM

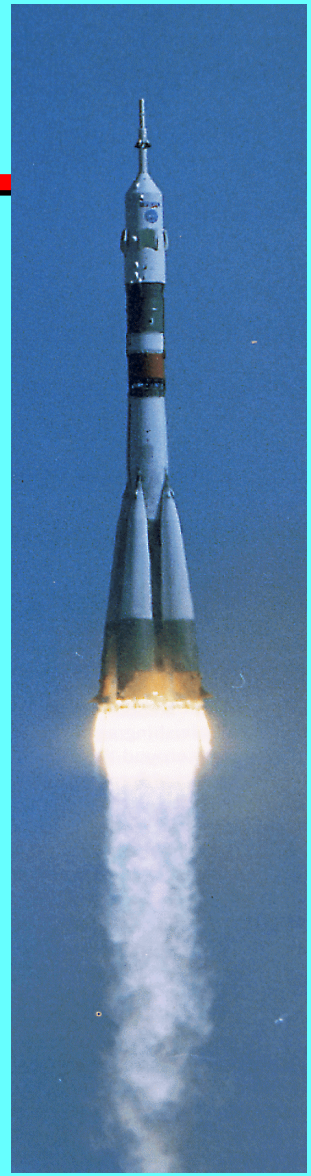
In Situ Resource Utilization



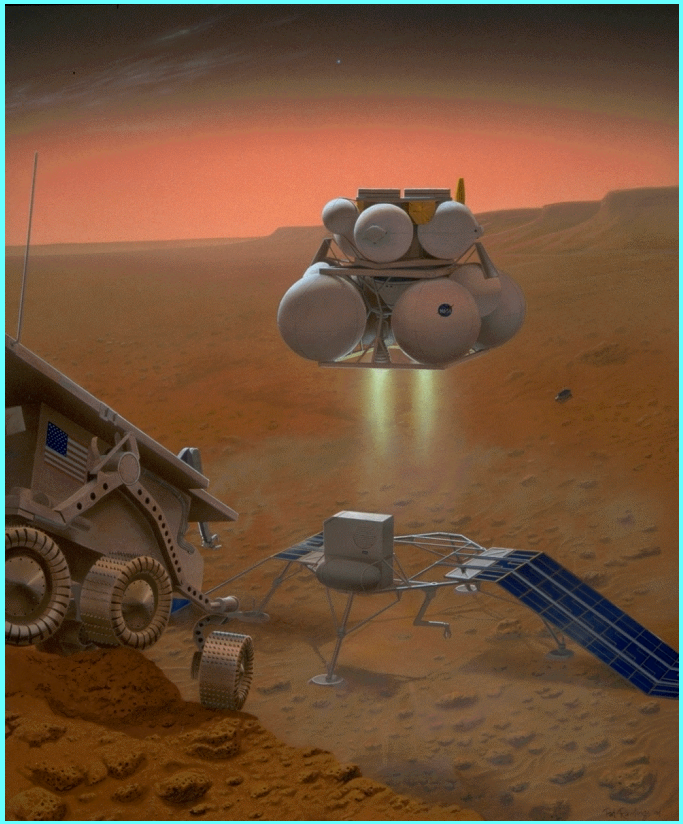


Cost of Space Exploration/Utilization

- To put payload in lower Earth orbit: $7,500 to 10,000 per pound
- In Situ Resource Utilization (ISRU): Using indigenous space resources



Mars Sample Return Mission Uses In Situ Propellant Production



CO_2 Conversion Processes

Sabatier Reaction

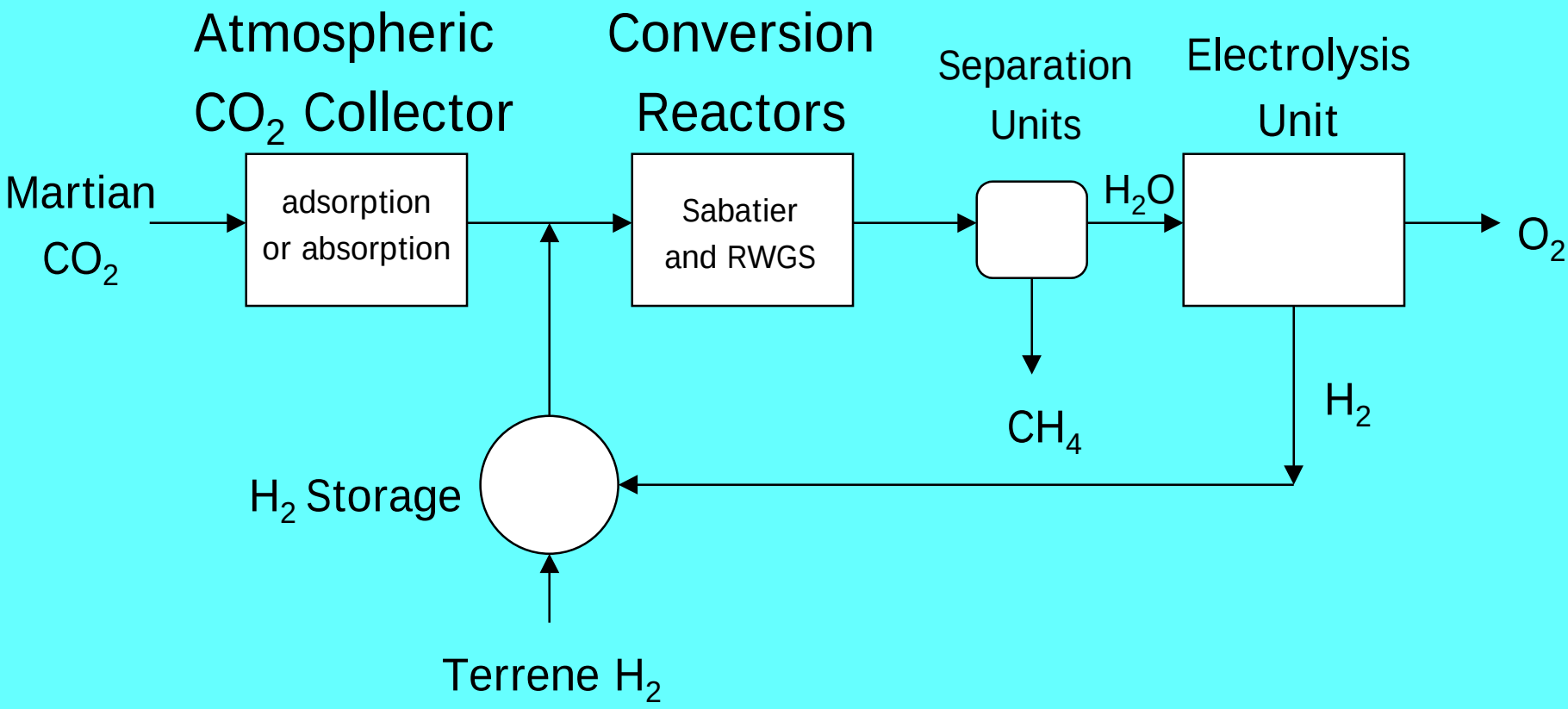
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

- light, transportable H_2 will be brought from Earth

Reverse Water-Gas Shift Reaction

$$CO_2 + H_2 \rightarrow CO + H_2O$$

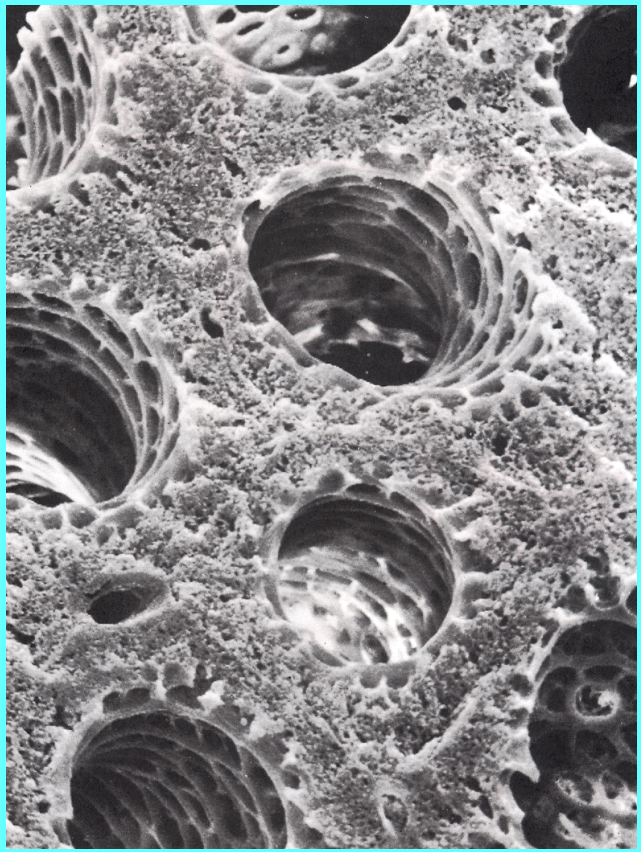
System Design

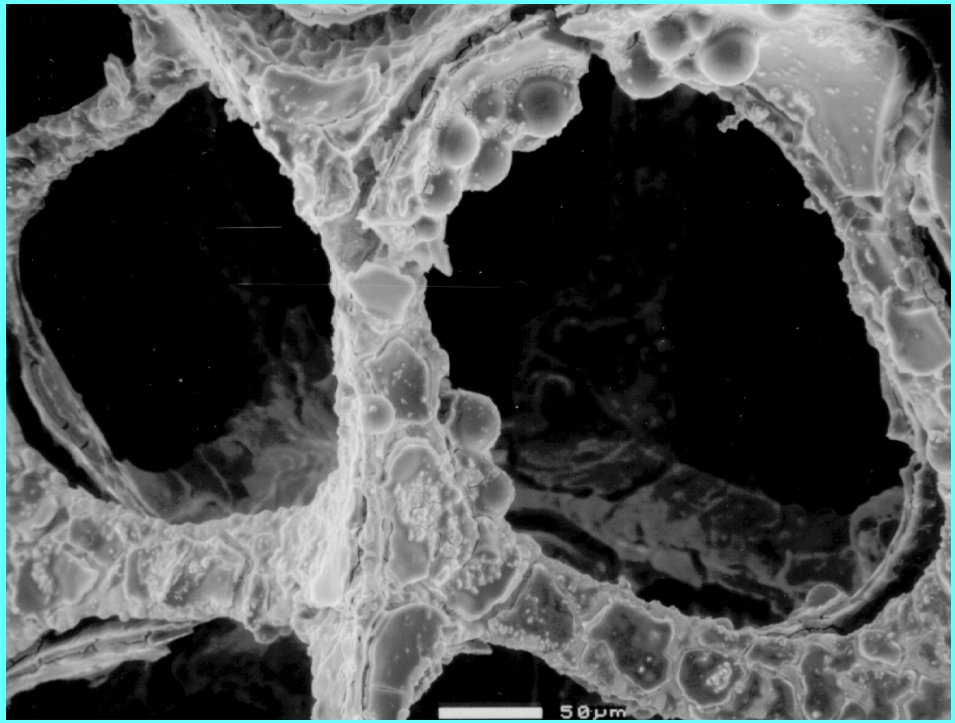


MICRO-CATS in the 21st Century

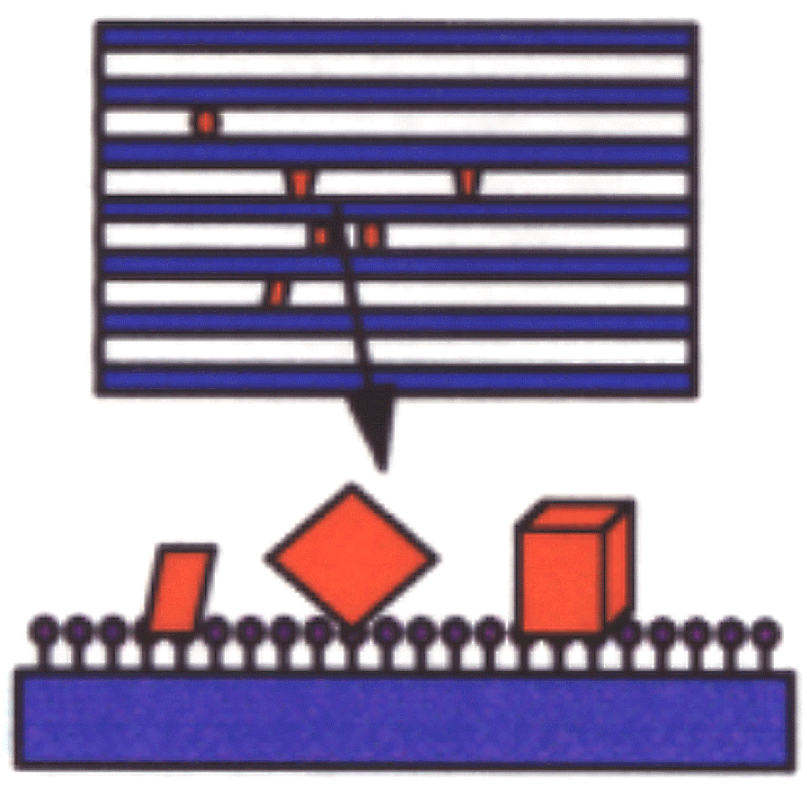
- Engineered Nanosystems
- Enzymes and Functional Surfaces
- Future in Space

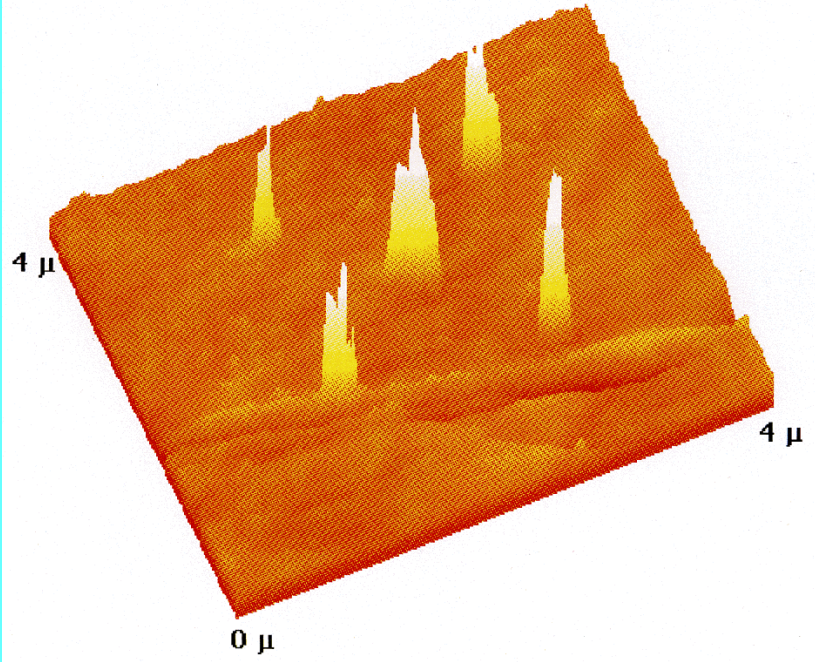
Highly Functional Surfaces and Coatings



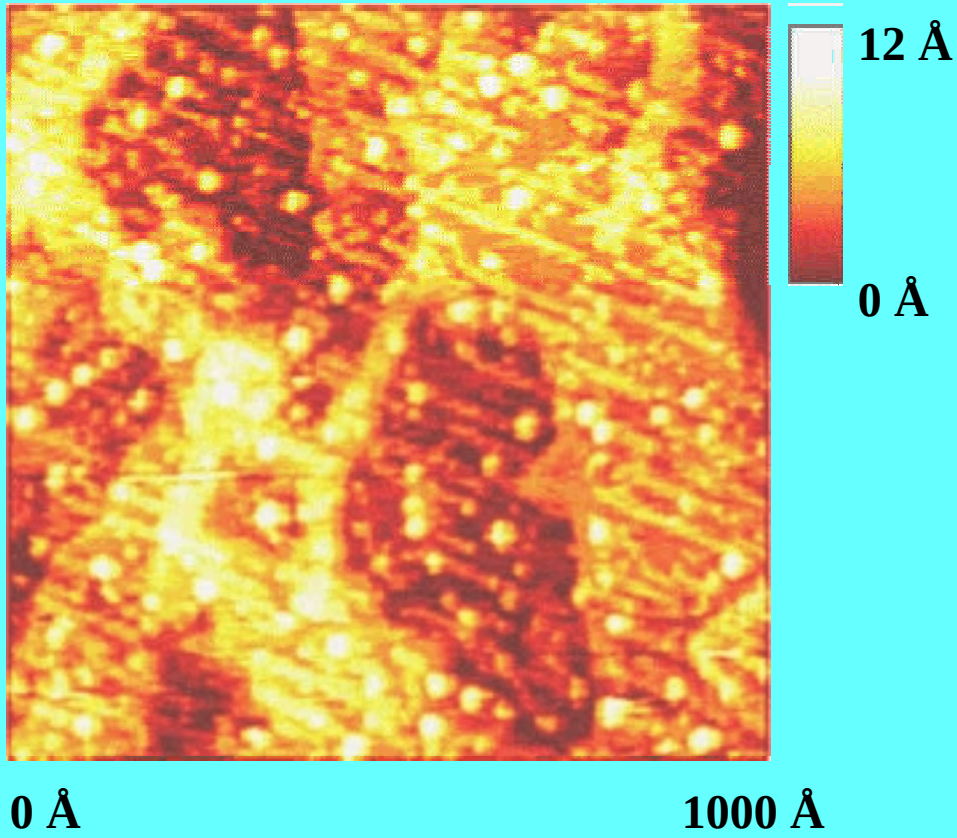


Highly Functional Surfaces and Coatings





Engineered Catalysts



Commercializing Nanotechnology

The U.S. Nanotech Nine

COMPANY	LOCATION
California Molecular Electronics	1997 startup; San Jose, CA
IBM	Research centers in Yorktown Heights, NY, San Jose, CA, and Zurich
Motorola	Tempe, AZ
Nanogen	San Diego, CA
Nanologic	Walnut Creek, CA
Raytheon Systems	Dallas, TX
Nanophase Technologies	Burr Ridge, IL
Hewlett-Packard	Palo Alto, CA
Zyvex	Richardson, TX

Future in Space