MICRO CHEMICAL AND THERMAL SYSTEMS (MICROCATS) BEYOND 2000

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AICHE SPRING NATIONAL MEETING

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U.S. Department of Energy
Pacific Northwest National Laboratory

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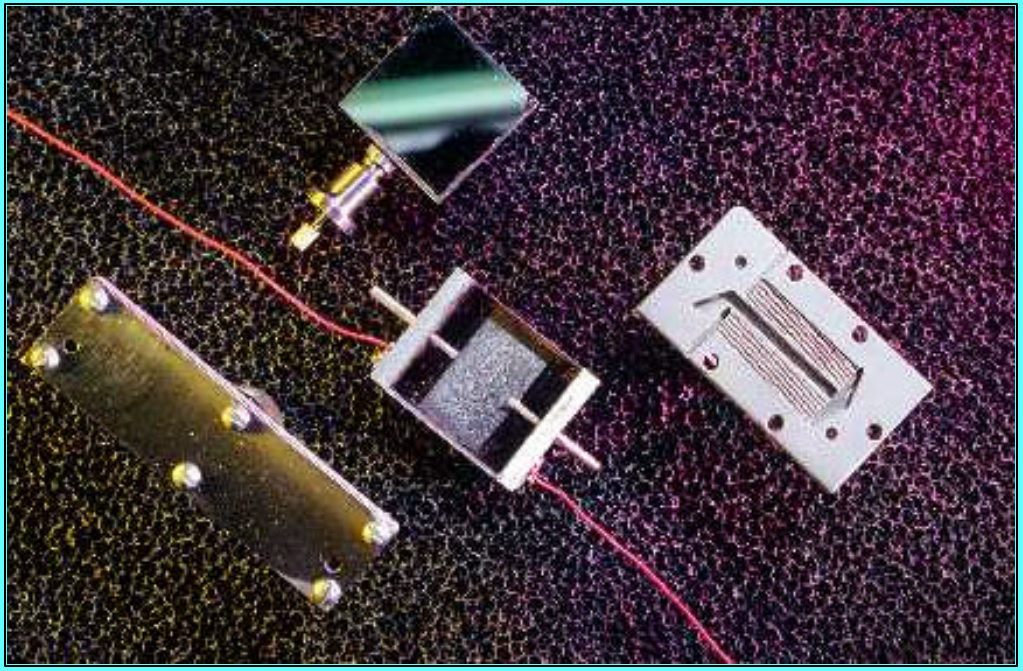
New Tools:
Micro Chemical and Thermal Systems

- Microchannel Heat Exchangers, Reactors and Separations units
- Miniaturization:
  - Process Intensification
  - High capacities
  - Lightweight systems
  - Mass Production



DARPA:	MEMS, Mesoscopic Machines
NASA:	Micro/Nano Systems
Department of Energy	Microcats

Contents

- Component development and systems engineering
  - Unit operations
  - Development principles
  - Technical details…
- A couple of reasons to develop microcats…
  - On earth
  - In space
- R&D Challenges
  - Technical barriers, near and long term
  - Programmatic difficulties
- Summary & Conclusions

Microcomponent Unit Operations and Micro Systems Engineering

- Unit Operations
  - Micro/microchannel mixers
  - Micro/microchannel heat exchangers
  - Micro/microchannel gas absorbers and adsorbers
  - Micro/microchannel catalytic reactors
  - Micro/microchannel electrochemical reactors
  - Micro/microchannel gas/liquid separations
  - Other micro/microchannel reactors and separators
  - Micro valves, pumps, fans and compressors
- System Architectures
  - Temperature Control; Reaction Control
  - Thermal Integration; Efficient Energy Utilization
  - Parallel Operation; High Process Rates

Three Important Development Principles…

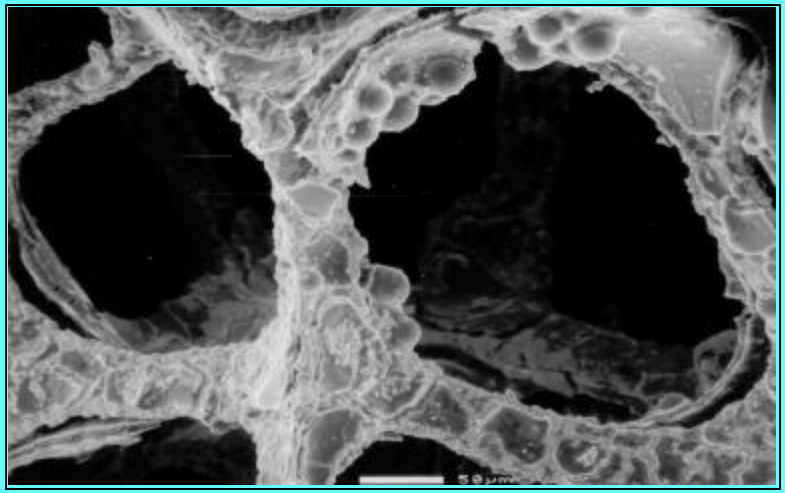
1. Strong analogies to biological systems
   - Similar scale
   - Similar unit operations
   - Not all things are micro
   - Broader range of materials from which to choose

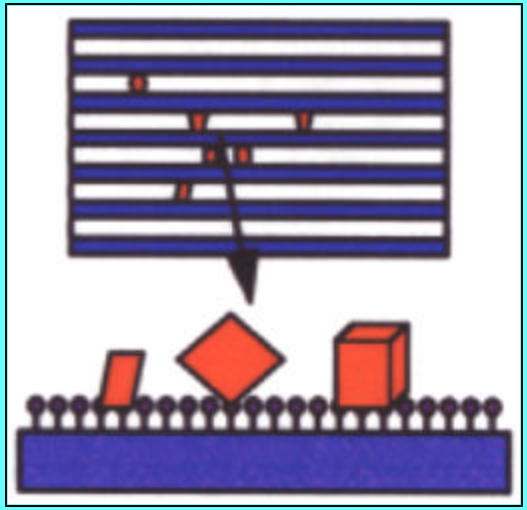
Three Important Development Principles…

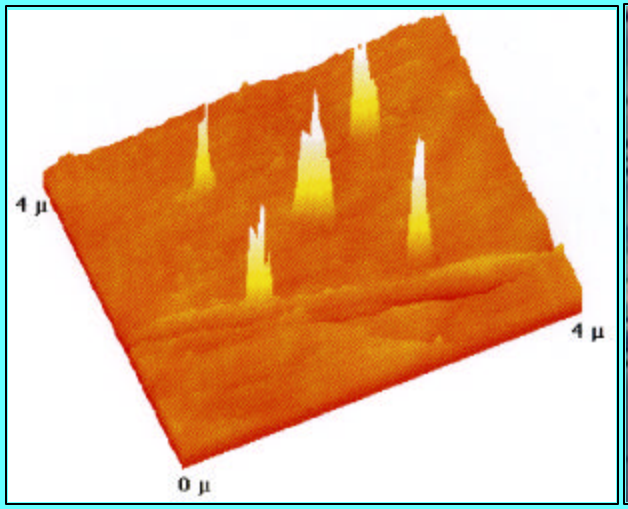
2. <u>Integrated chemical process chips</u>
   - Multiple reactors, separators and heat exchangers, in parallel and in series
   - Enabling for chemical processing what integrated circuit electronics enabled for computation
     - Intensive processes
     - Economies through mass production
     - Distributed applications

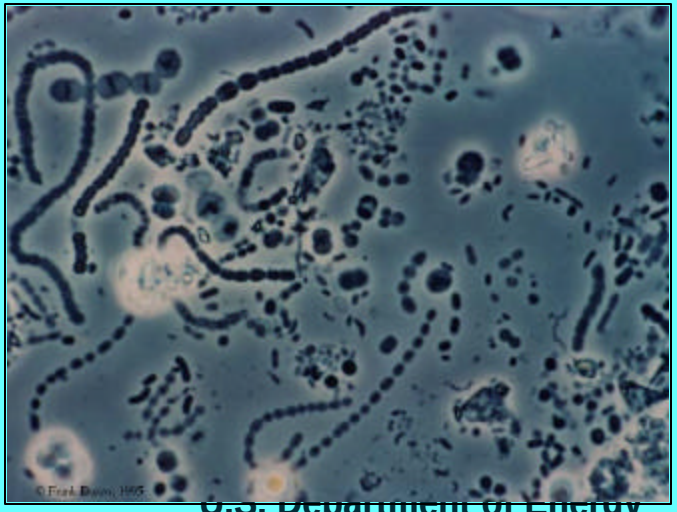
Three Important Development Principles…

3. <u>Platforms for enabling new technologies</u>
   - For analytical systems
   - For process intensification
   - For the application of nanotechnologies



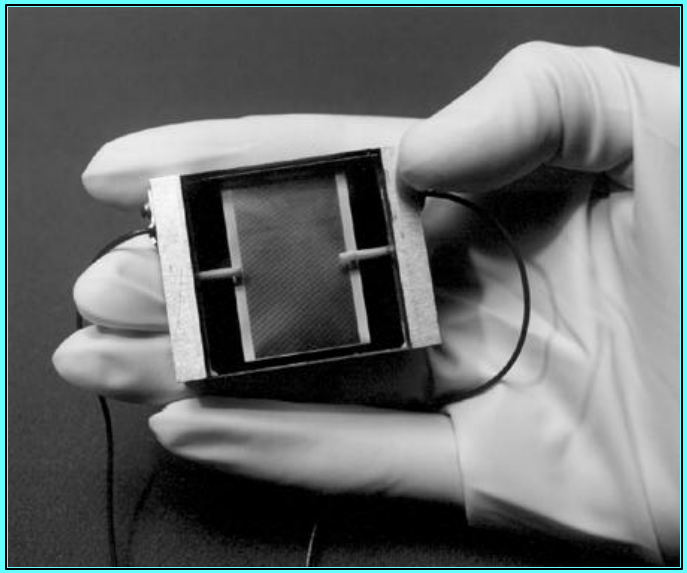


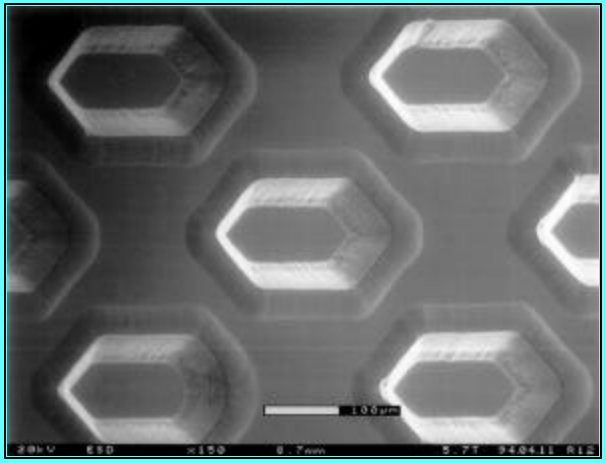


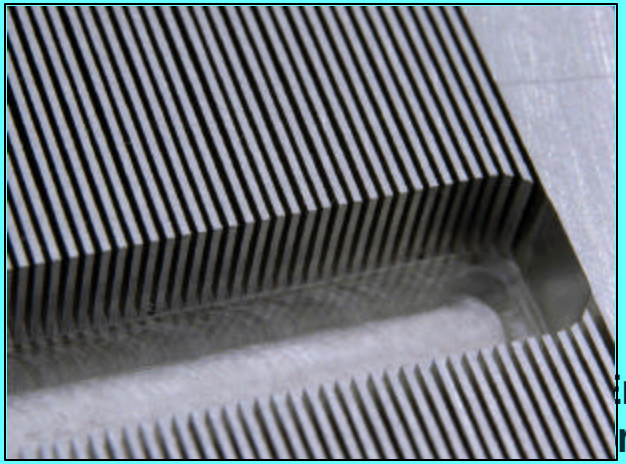


Advantage: Rapid Heat and Mass Transport
Microchannel Heat Exchangers

- 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

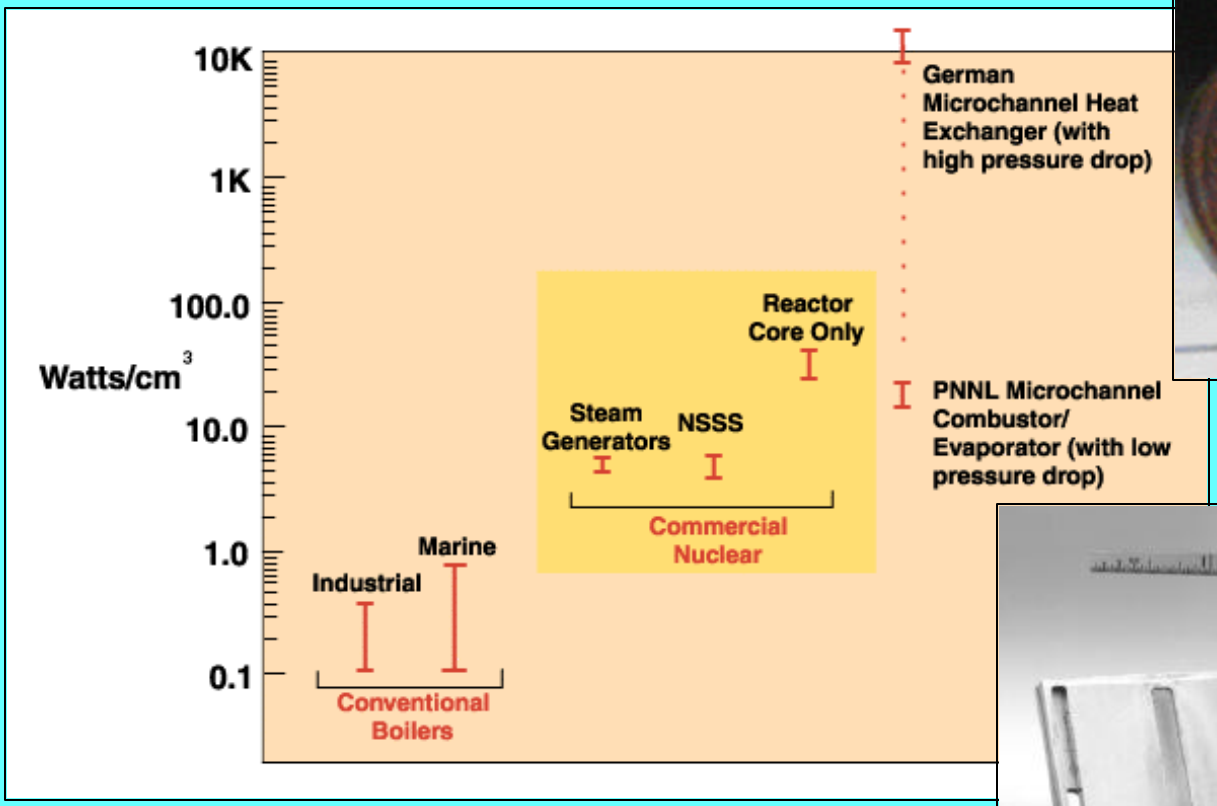


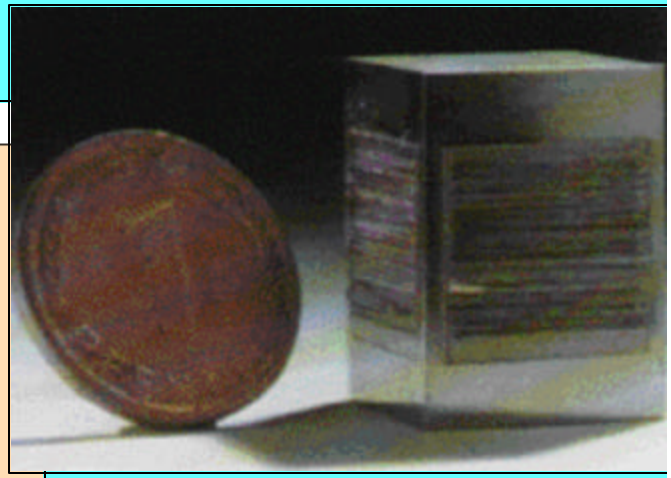


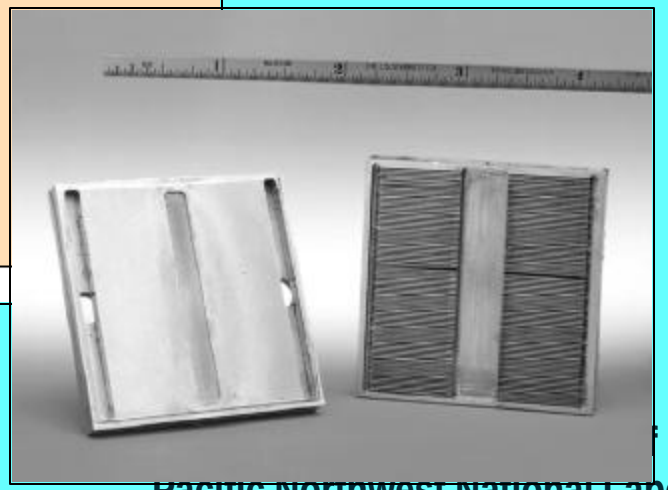


Heat Exchanger Duty

Heat transfer per unit hardware volume



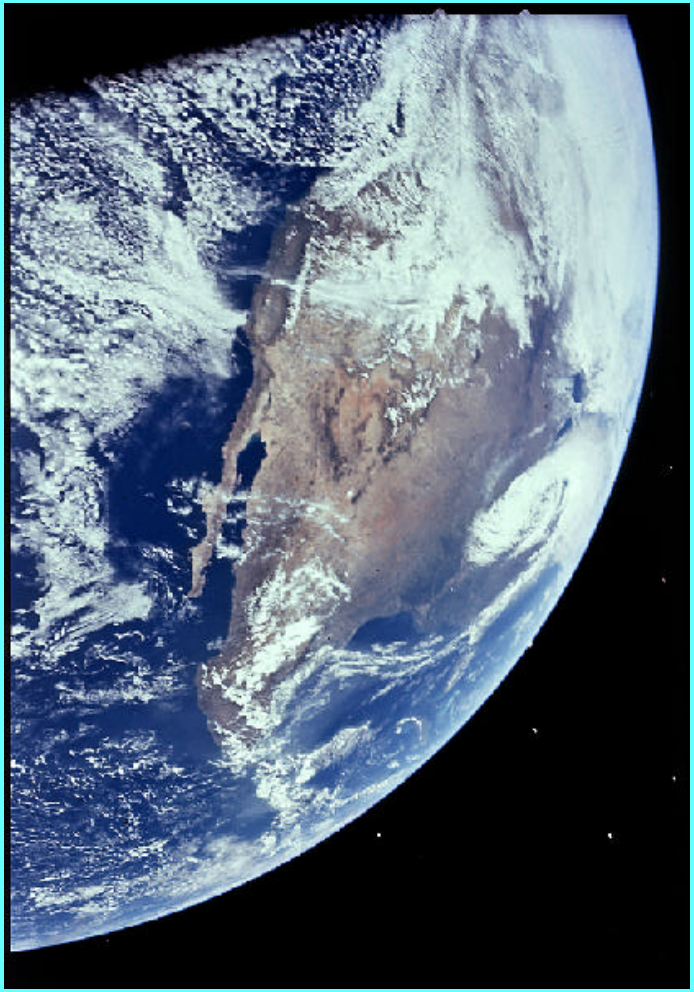




Multiple Fabrication Methods in Various Stages of Development

- Conventional micromachining (e.g., standard tools with small features)
- Photolithography
- LiGA, including injection molding, electroplating
- Laser micromachining
- Lamination and stamping
- Rapid prototyping methods
- Biomimicry methods (e.g., molecular self-assembly)
- Other nanoassembly (e.g, scanning tunneling microscopy, atomic force microscopy)

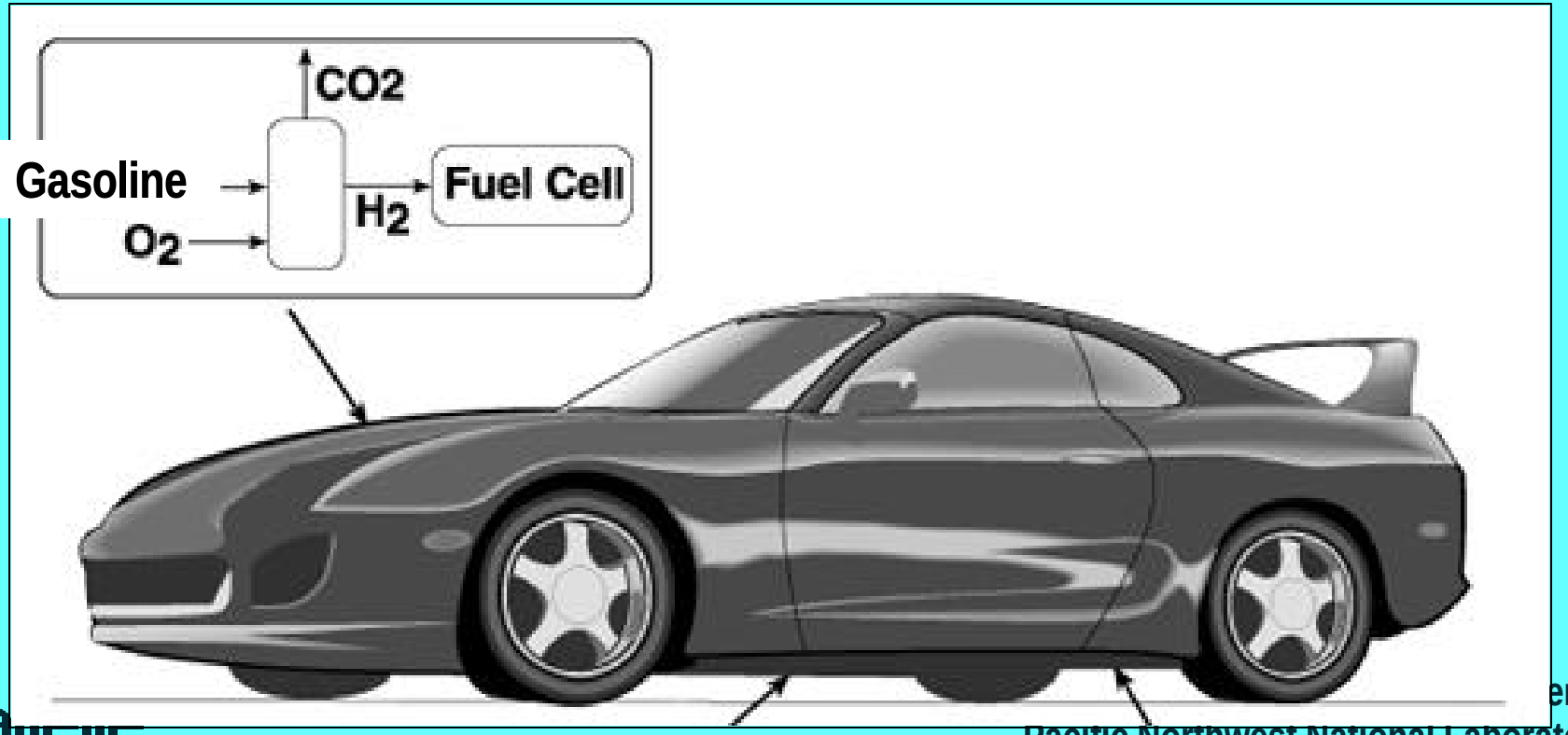
A Couple of Earth-Based Reasons for Developing Microcats…



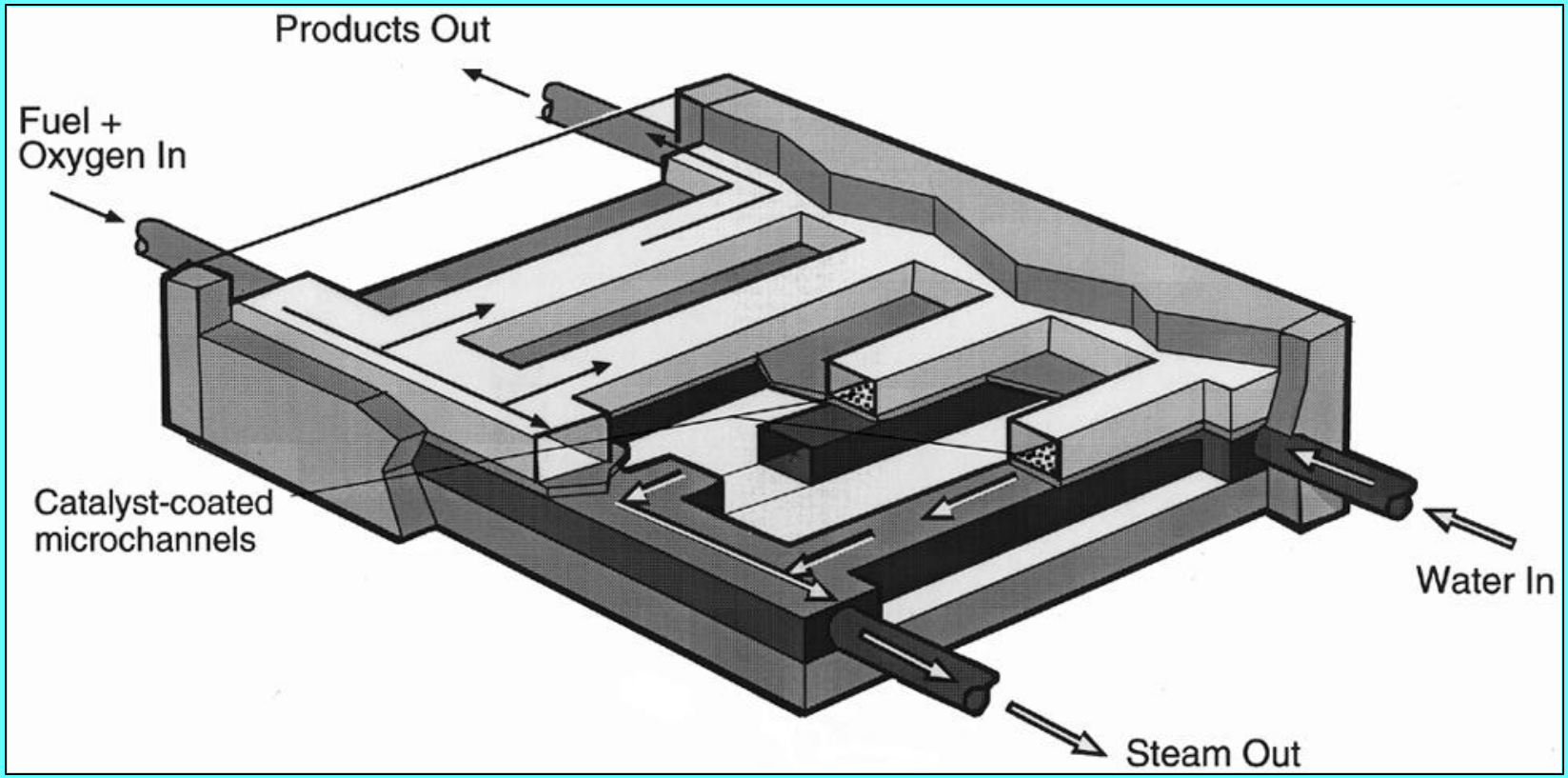
- Energy efficient use of petroleum
  - Technologies that could provide for improved transportation propulsion systems (e.g., fuel cells)
- Global warming
  - Technologies that could support the reduction of CO_2 emissions (e.g., potential capture of CO_2 for long-term sequestration)

Fuel Cell – Powered Automotive Systems

- Hydrogen may be the best fuel for the fuel cell, but it is not necessarily the best fuel for the automobile

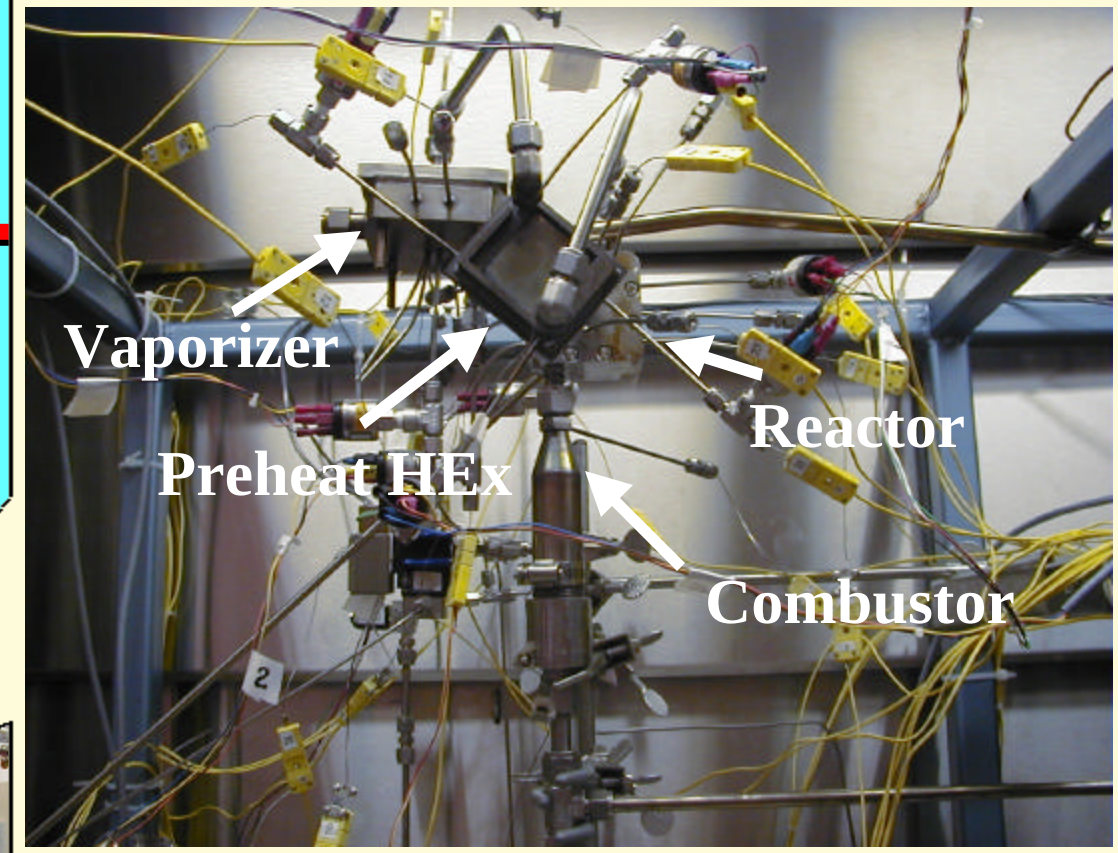


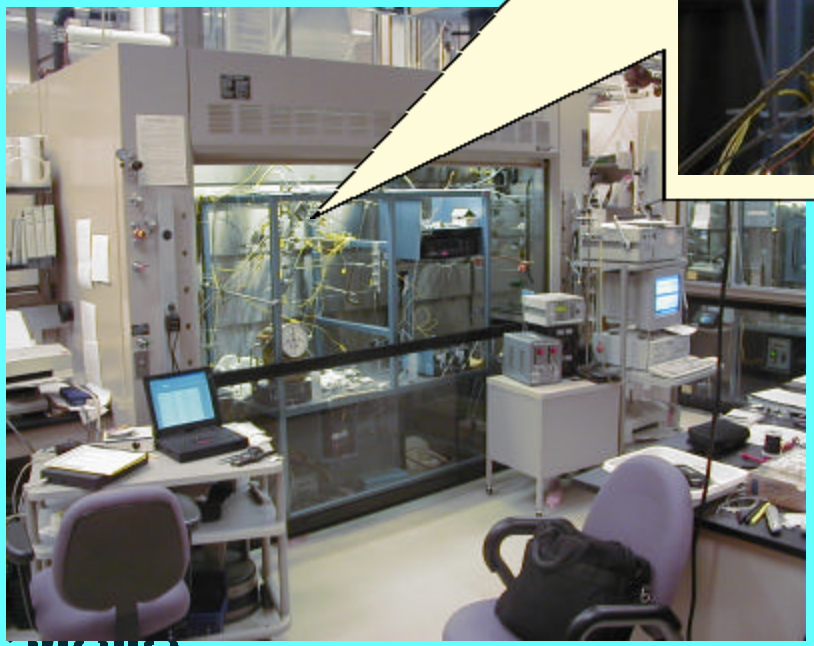
Microchannel Catalytic Reactors



Catalytic Microchannel Steam Reformer

Reactor cell volume = 29 cm^3





- Iso-octane steam reforming (gasoline simulant)
  - $C_8H_{18} + 8\ H_2O = 8\ CO + 17H_2$

    DH_r = 1345 kJ/mol

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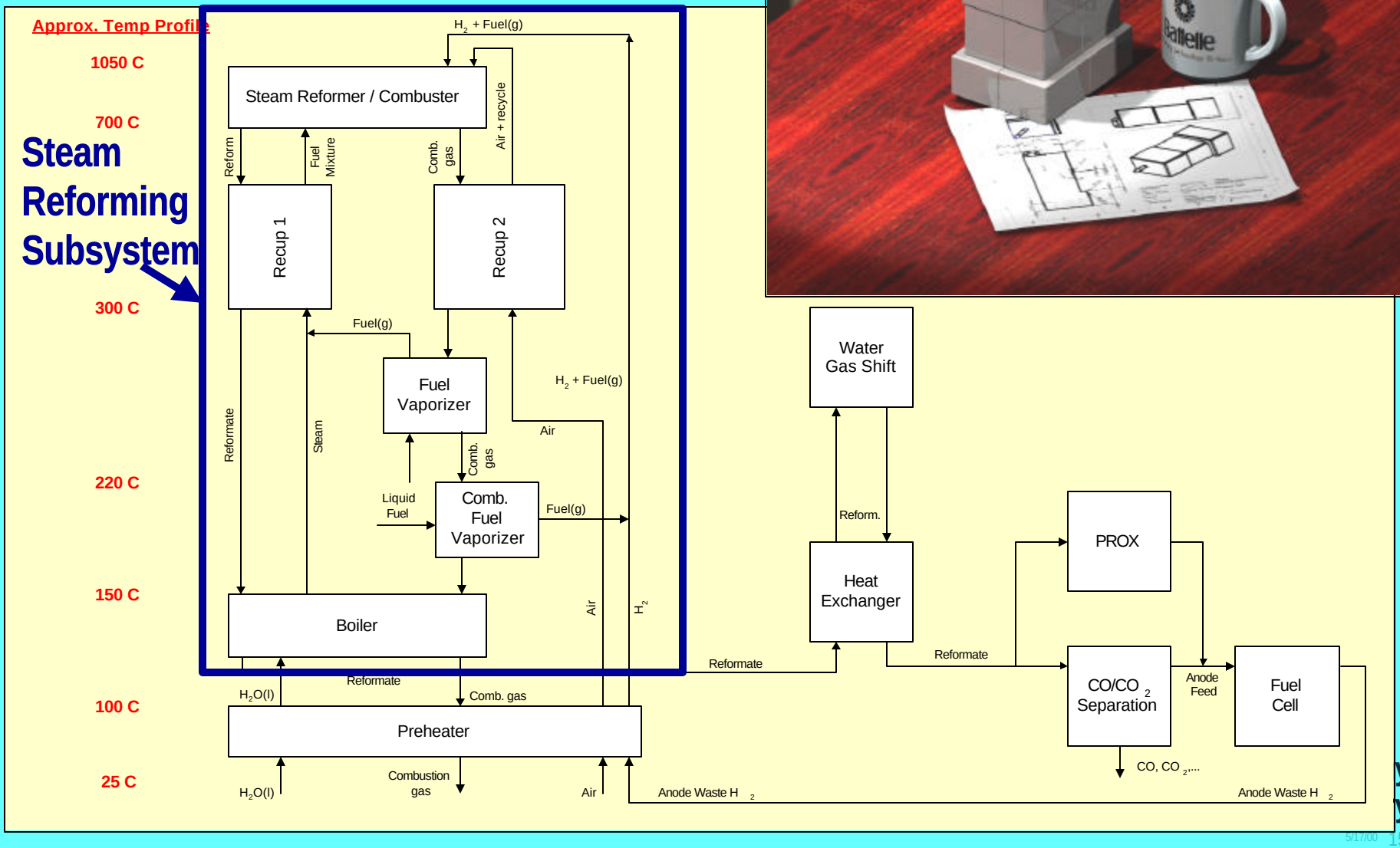
Catalytic Microchannel Steam Reformer



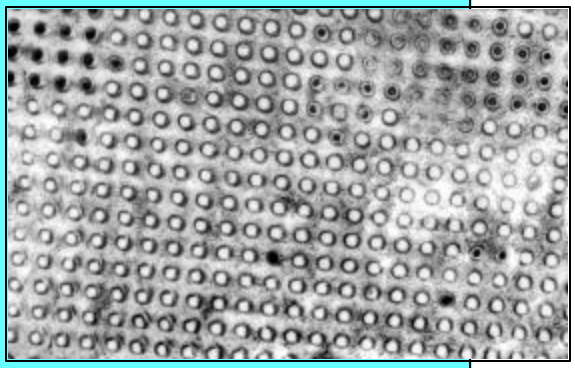
Global Carbon Management

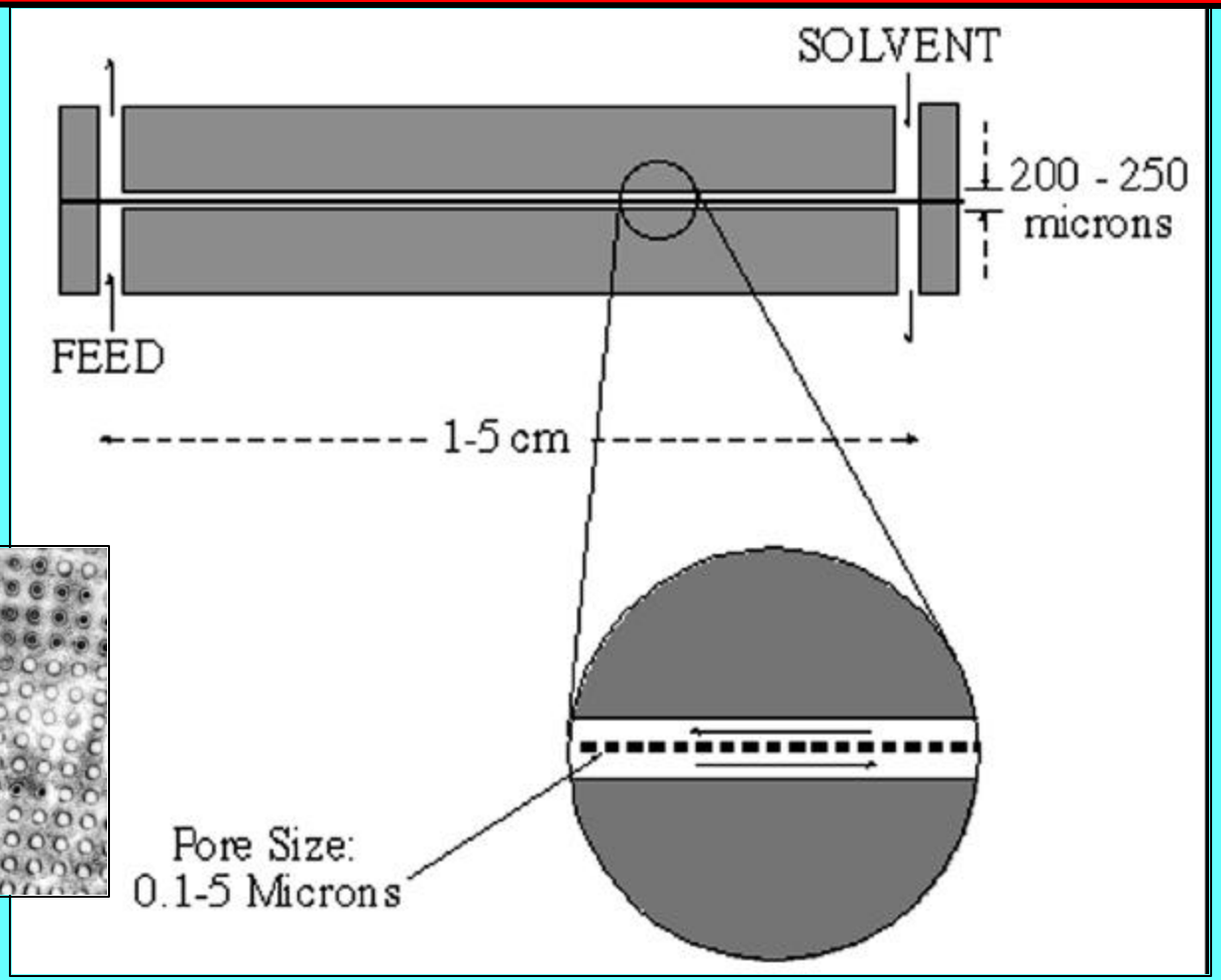
- Atmospheric CO_2 levels rising; concerns over possible global warming
- Fossil fuels inherently involve CO_2 generation
- International discussion includes long-term sequestration of CO_2

CO_2 capture and reinjection at an offshore platform in the North Sea

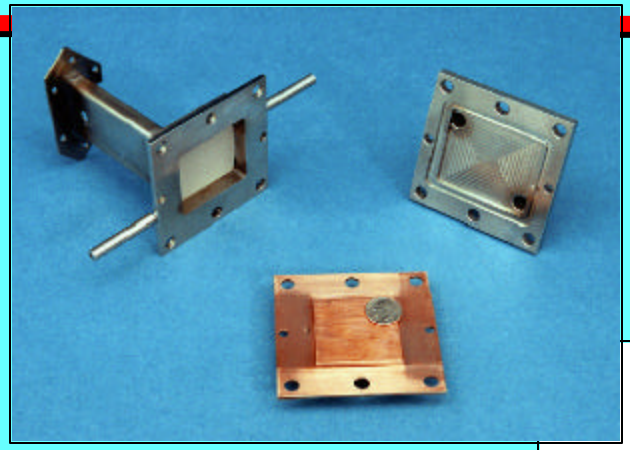
For CO_2 Collection: Microchannel Solvent Extraction and Gas Absorption Units

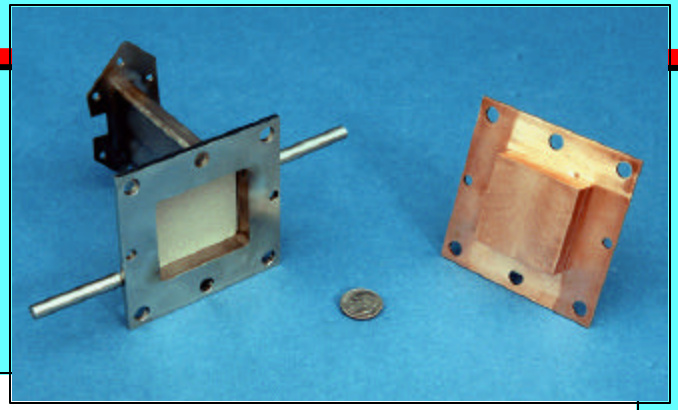
Micromachined contactor

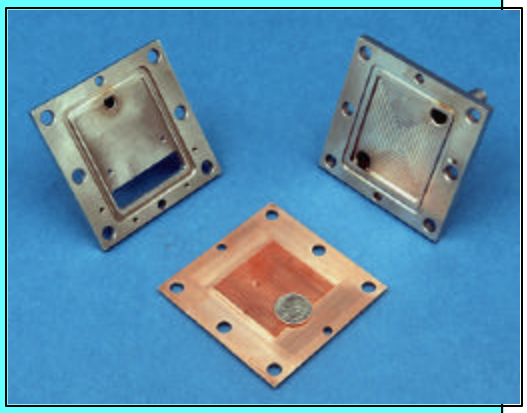


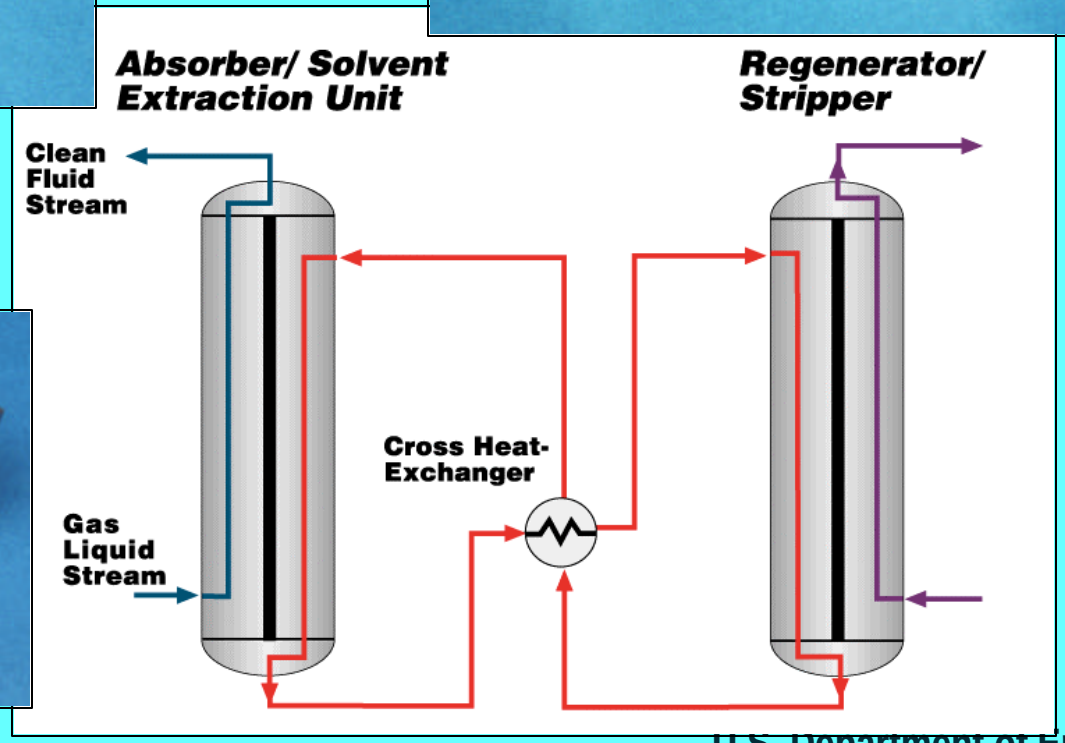


Development of Integral Systems for CO_2 Collection

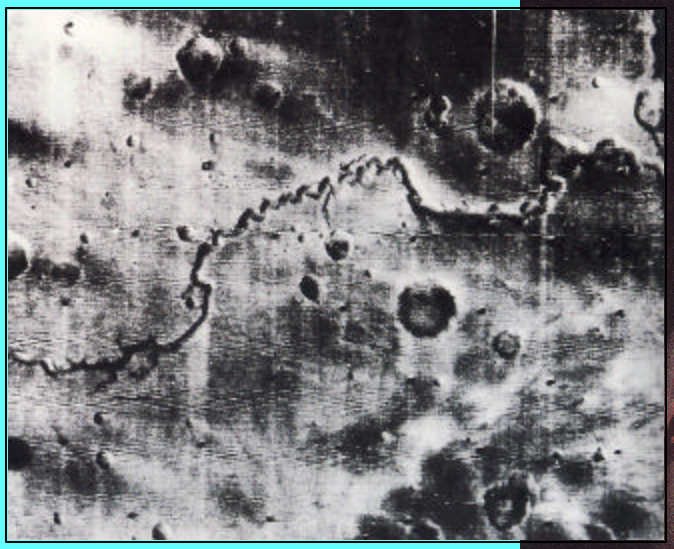


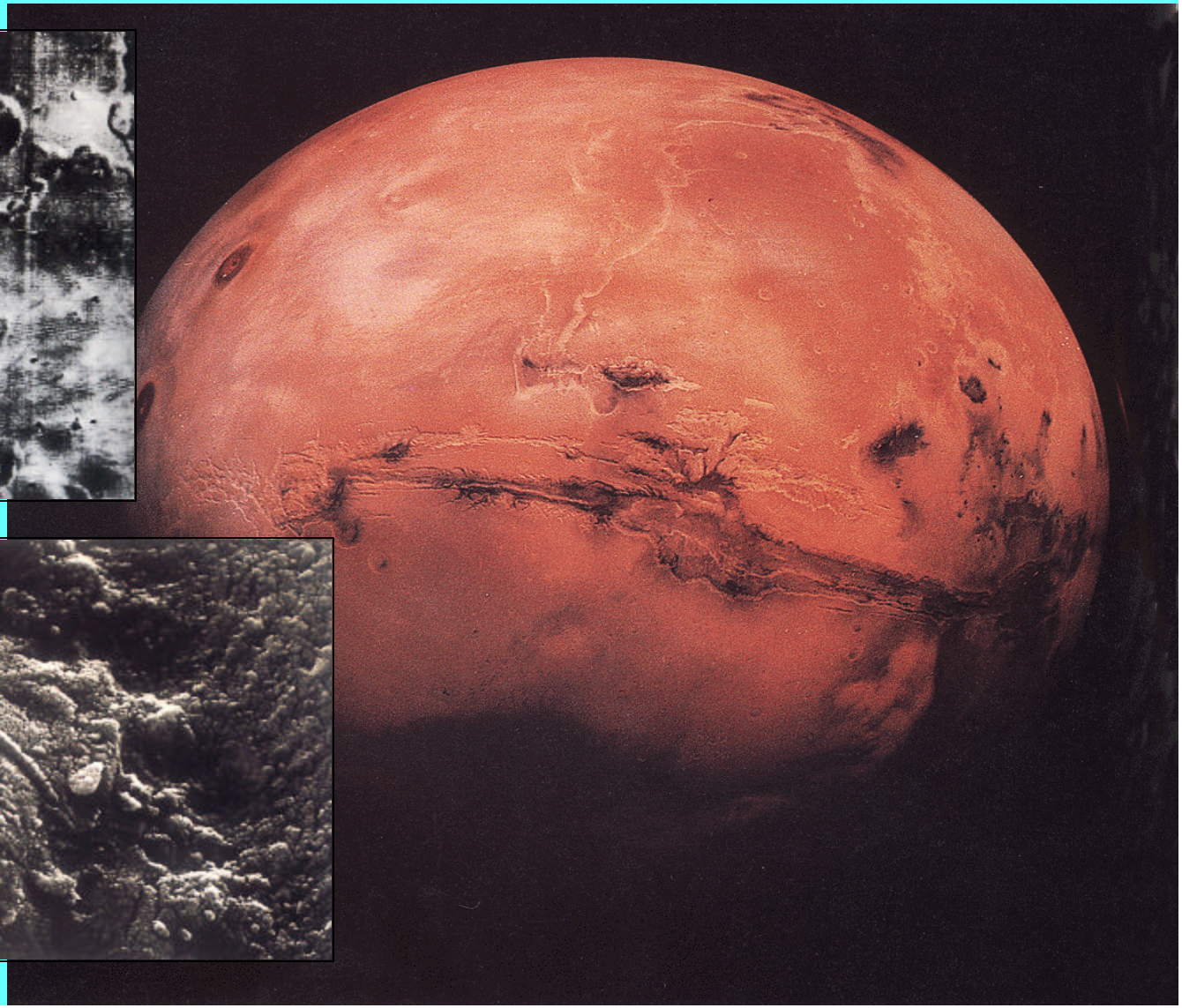






A Non-Terrestrial Reason: To Determine if Life Separately Originated on Mars…





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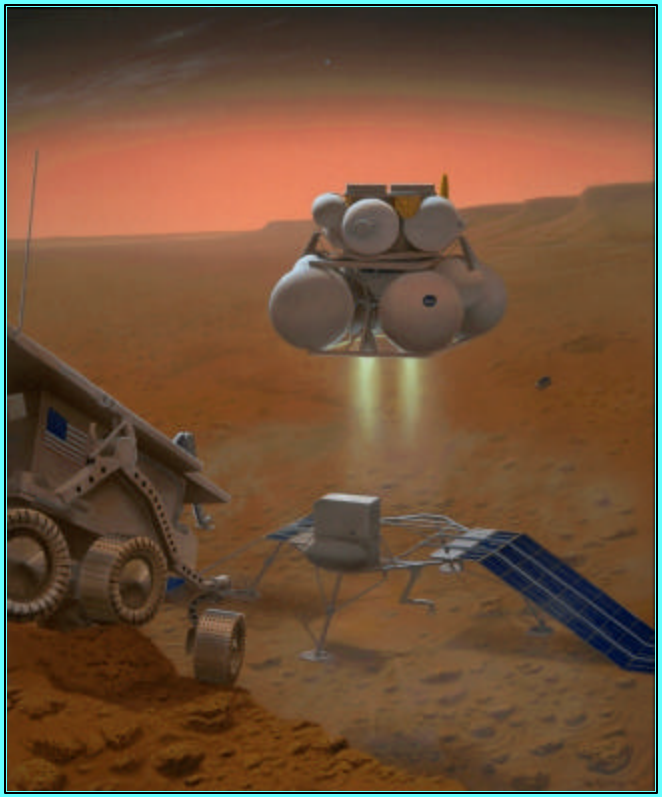
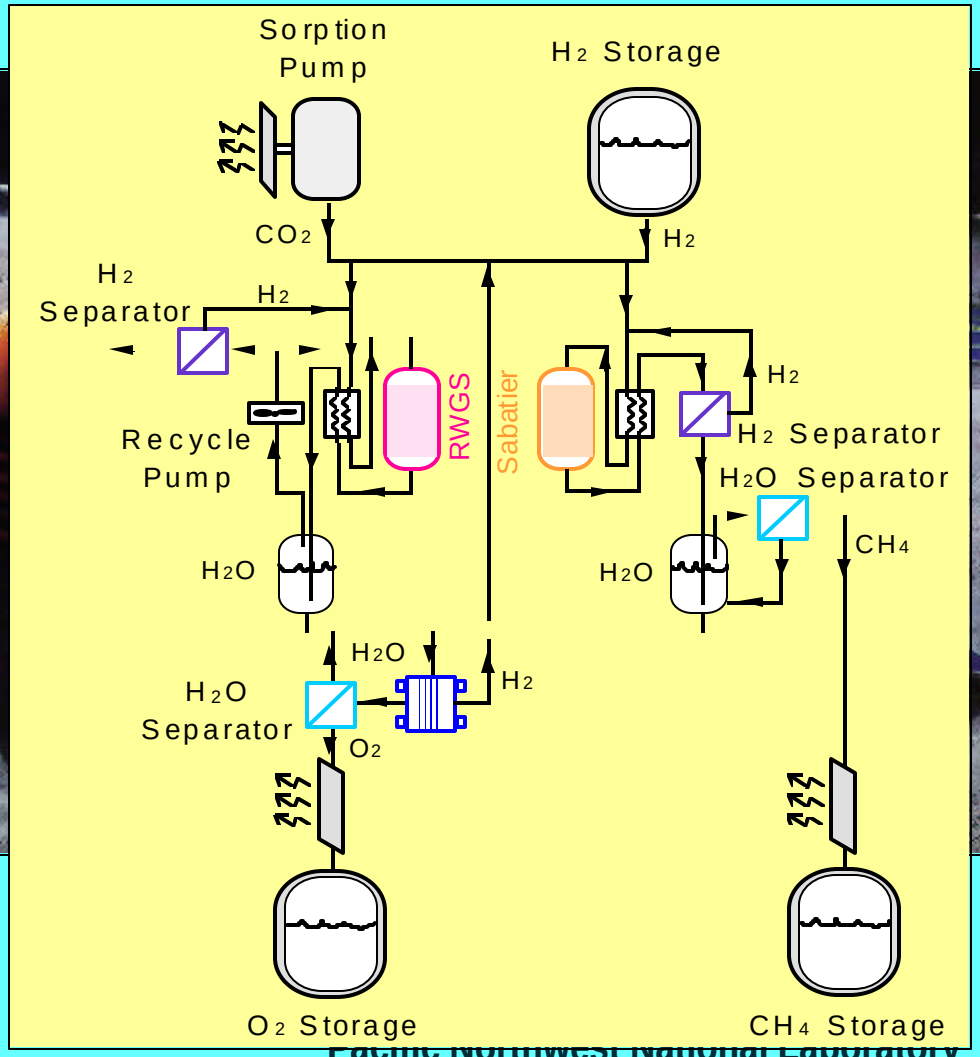
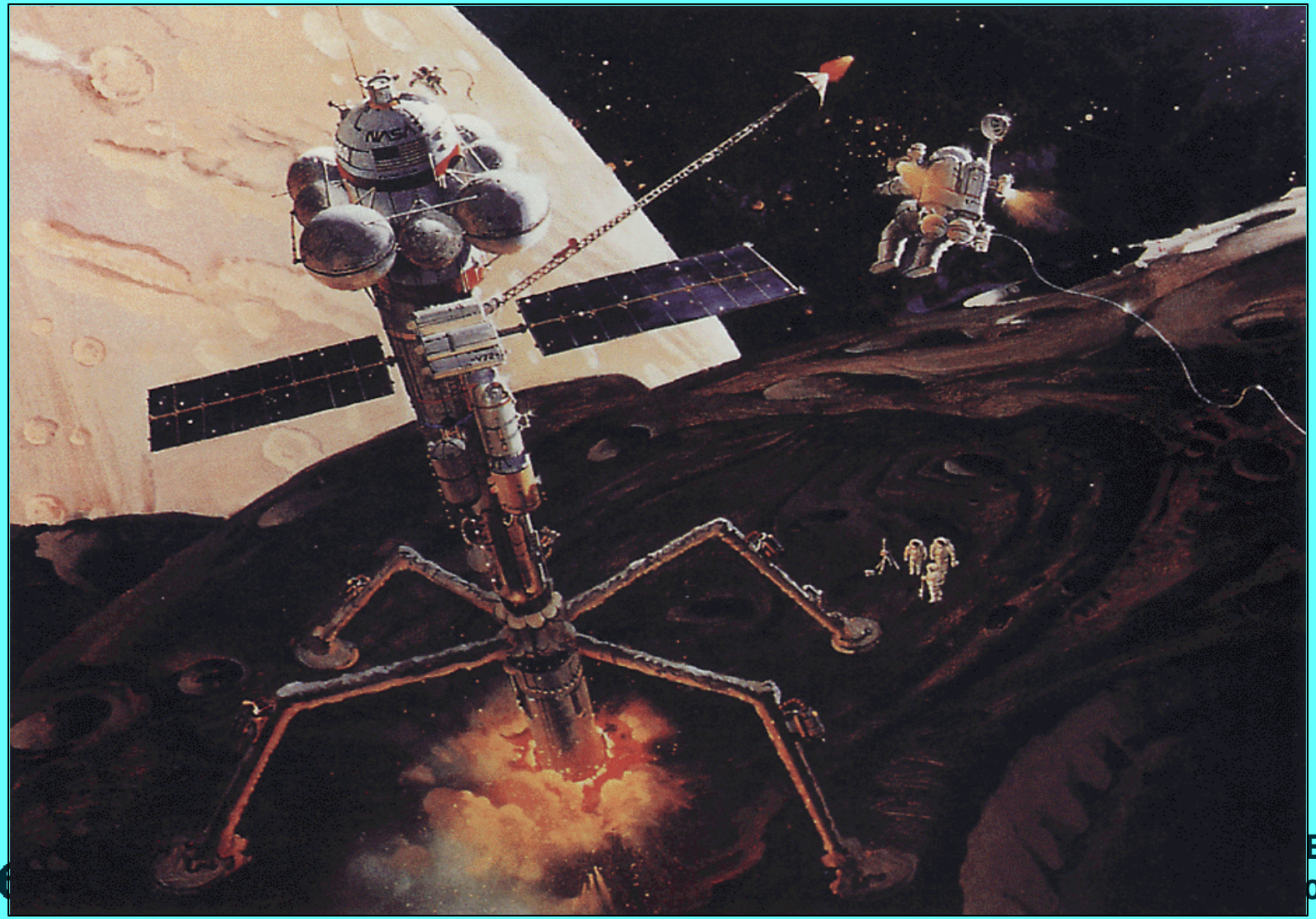
Distributed Processing for NASA: With In Situ Propellant Production





Utilization of Space Resources



Other Development Areas

- Manportable cooling (e.g., heat pumps) and power generation (e.g., battery replacements)
- Comodity and specialty chemicals production
- Pharmaceuticals production
- Point of use / Just-in-time production of toxic, hazardous feedstock materials
- Analytical Systems

Technical Challenges: Near-Term Research and Development Areas

- Micro-Fluidics and Heat Transfer
- Surface Effects / Forces
- Engineered Catalysts
- Peripherals
  - Pumps, valves, compressors, fans, etc
- Reliability, Maintainability
  - Fouling
- Low Cost Manufacturing Methods

Technical Challenges: Longer Term Research and Development Areas

- There is still "plenty
  the incorporation of
  - Facilitated transport
  - Self-assembling, re
    for control of fluid fl
  - Molecular ion chan
  - Enzyme and enzym
  - Localized control of
  - Quantum physics/c

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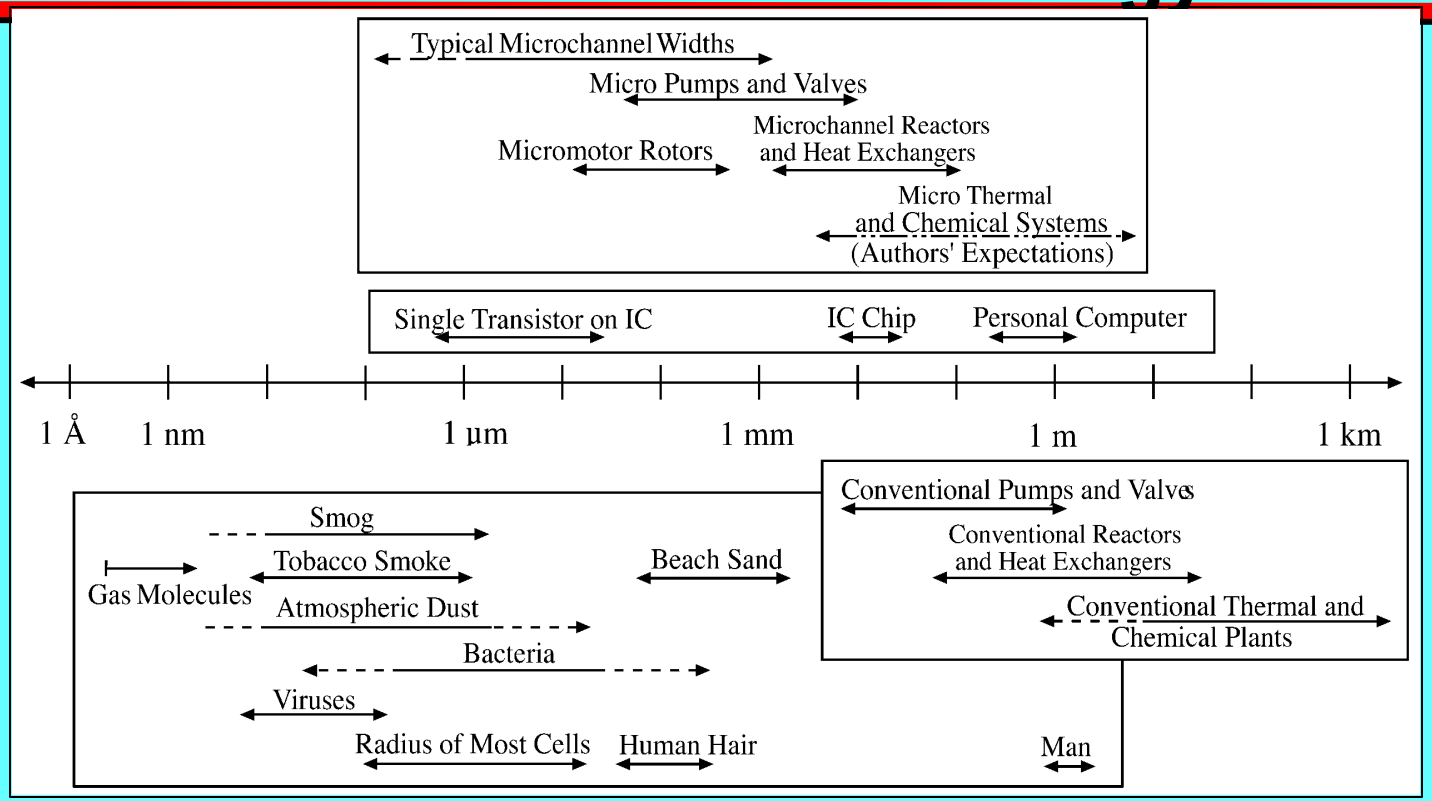
Programmatic Challenges

- To develop and commercialize microcats…. We need more chemical and mechanical engineers that are trained in the area of microcats!
- Fortunately, we can grow and train them…
  - We are beginning to with universities to develop suitable curriculum for micro chemical engineering training

MicroCATS:
A New Era in Process Technology



How will society use energy and chemicals when process technology is compact and lightweight, with low capital costs (through mass production) and short lead times for deployment?