Advances in Microchannel Contactors for Chemical Separations

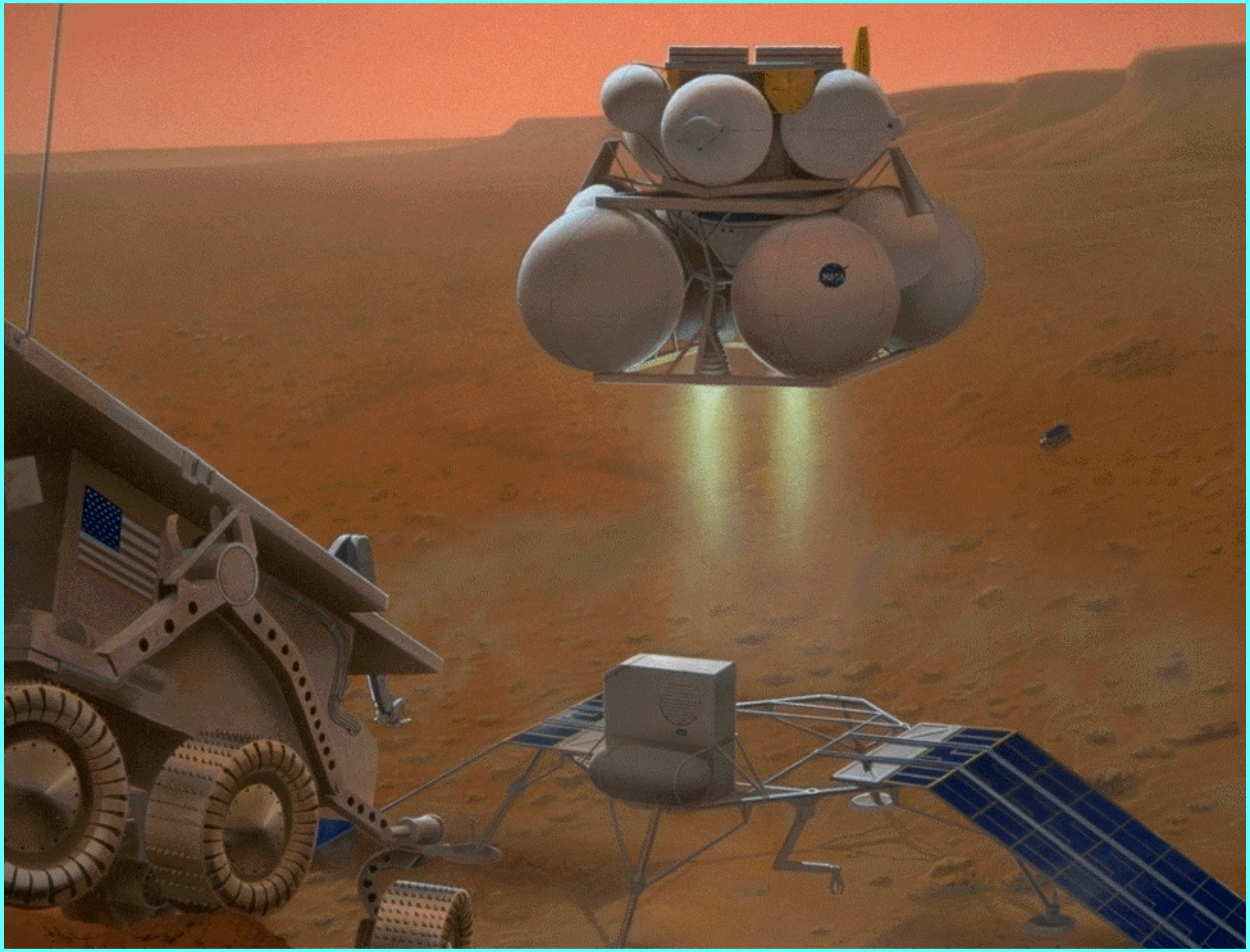
W.E. TeGrotenhuis, R.J. Cameron, V.

Pacific Northwest National Laboratory

Richland, WA

April 1999

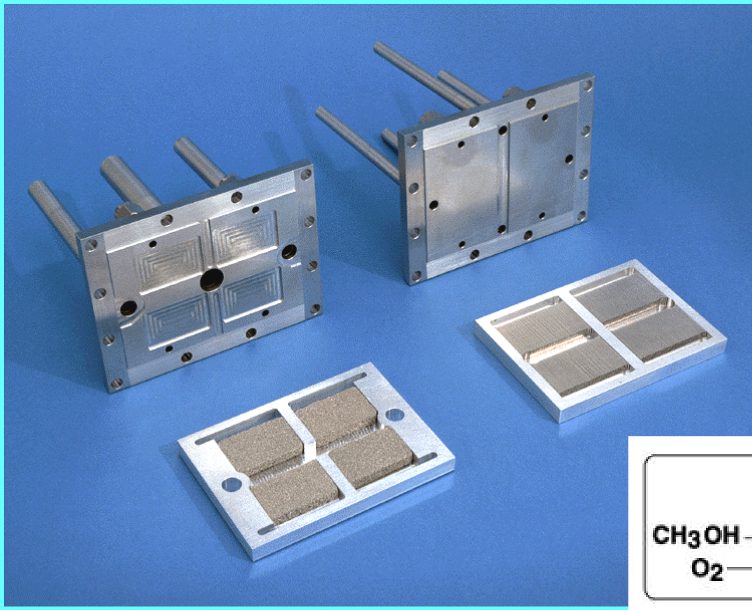
Applications
NASA - In Situ Resource Utilization

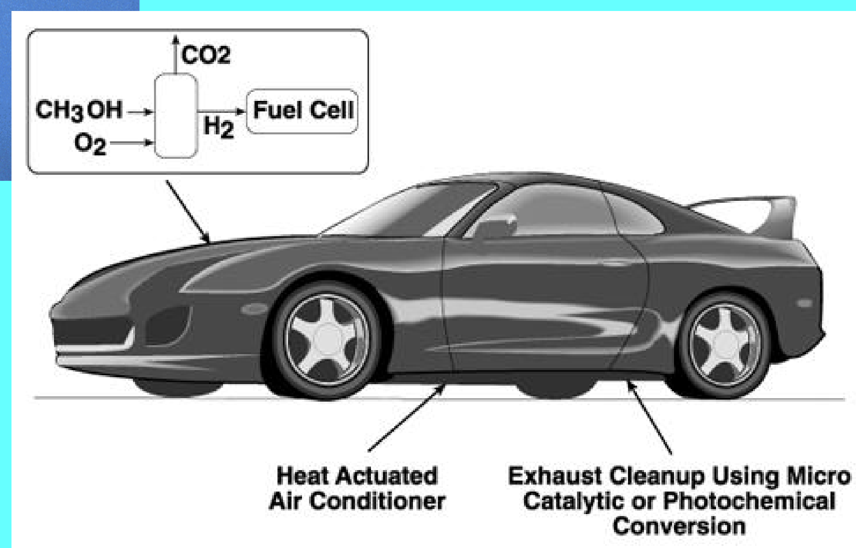


U.S. Department of Energy

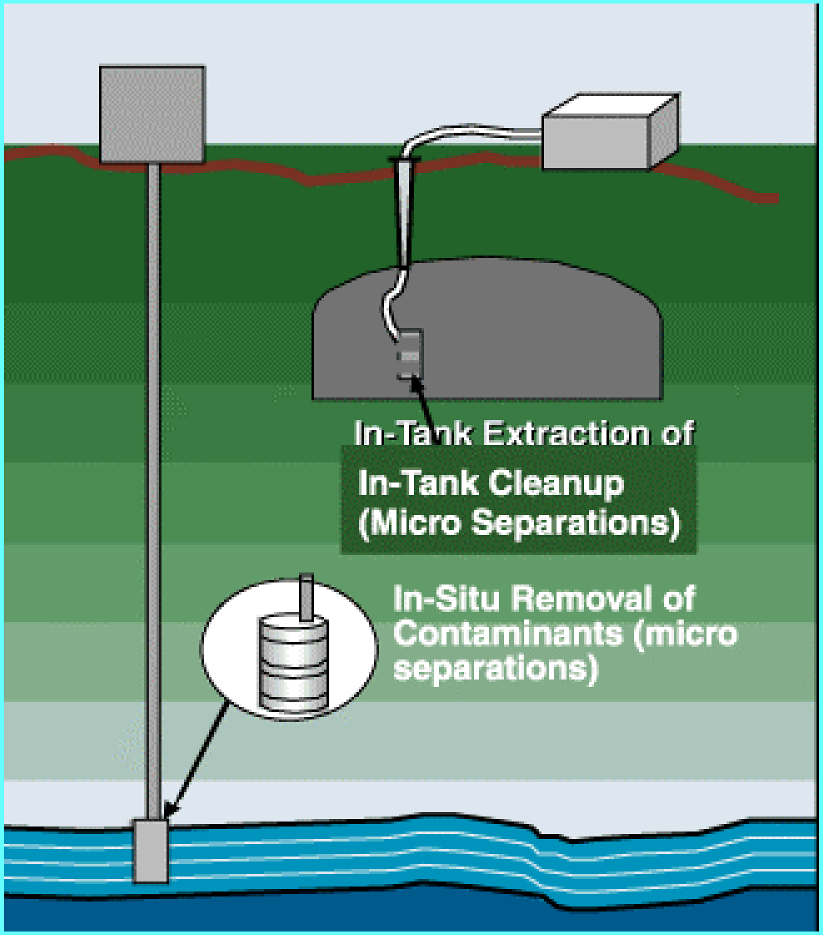
Battelle

Applications
Onboard Fuel Processing





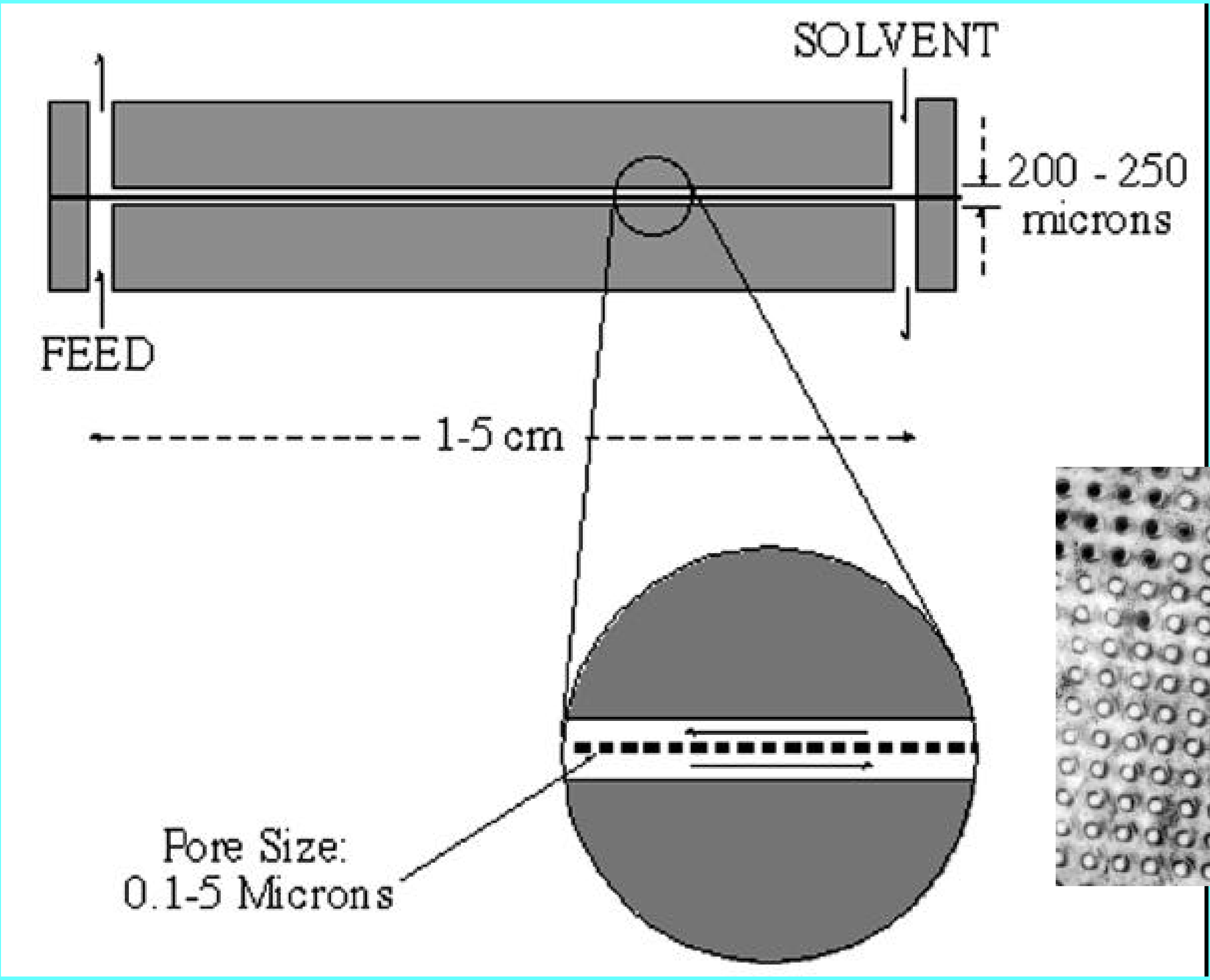
Applications
Waste Processing

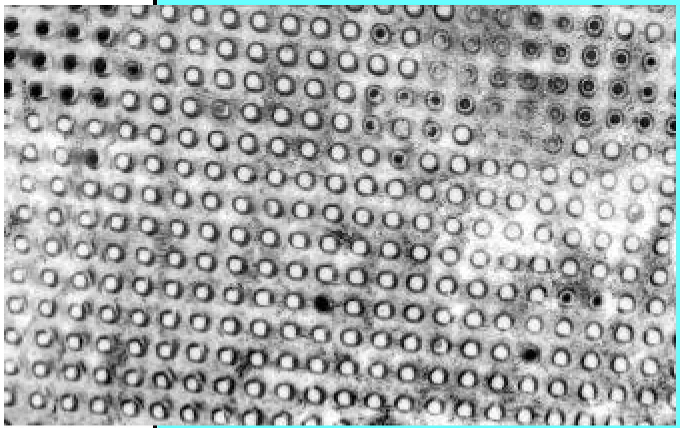


Battelle

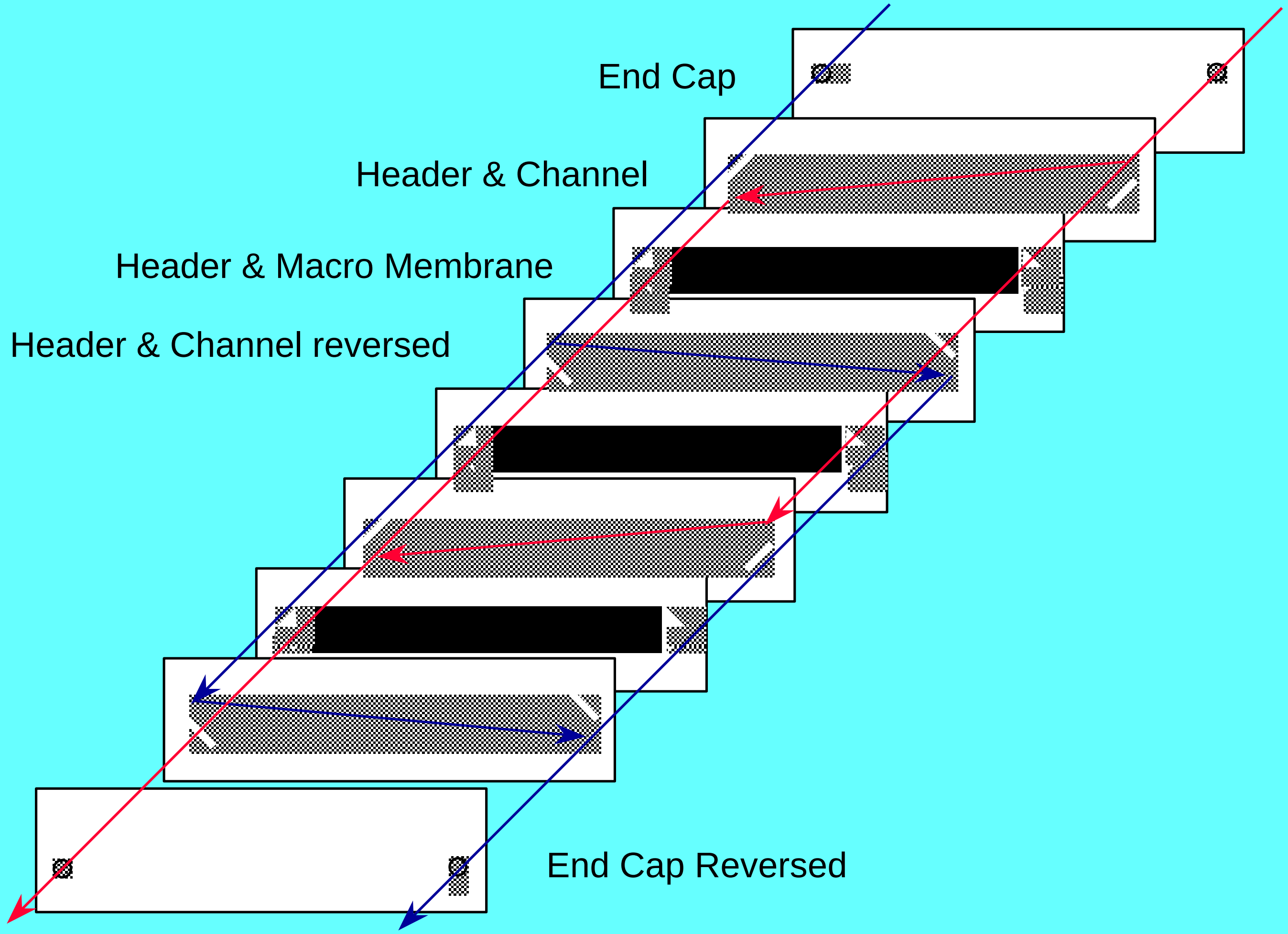
- Microchannel Contactor for Separations
- Hanford Tanks
  - Solvent Extraction
- Summary

Microchannel Contactor





Microchannel Architecture



Battelle

U.S. Department of Energy
Pacific Northwest National Laboratory

Microchemical Processing
Advantages

- High Capacity (throughput per unit hardware volume)
  - Rapid heat transport
  - Rapid mass transport
  - Short residence times
  - Smaller devices to get the job done
- Reduced Capital Cost through Economies of Mass Production
- Compact Size Enables Distributed Processing

Microcontactor Scaling

- Mass Transfer $$\frac{1}{Pe_m} = \frac{D_s}{V\,h} = \frac{w\,L\,D_s}{Q\,h}$$
- Pressure Drop $$\Delta P \propto \frac{L\,Q}{w\,h^3}$$
- Residence Time $$T_R = \frac{w\,h\,L}{Q}$$
- **Use constant ΔP curves to meet design objectives**

h	L	Q	ΔP	T_R	1/Pe
const	2	1/2	const	4	4
1/2	1/2	1/4	const	const	1/2
1/2	1/4	1/2	const	1/2	const

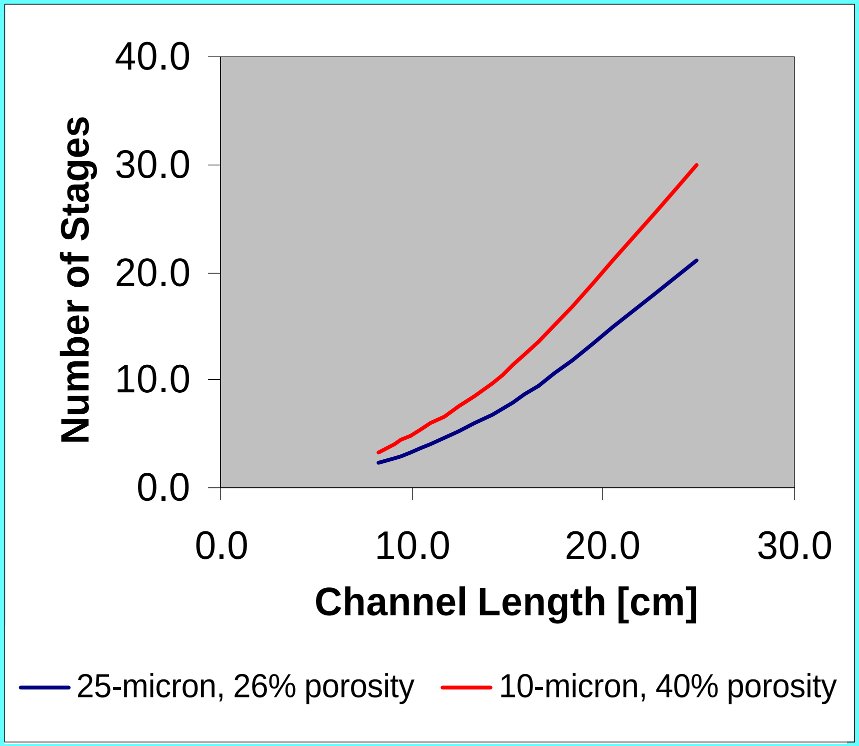
Microcontactor Design Approach

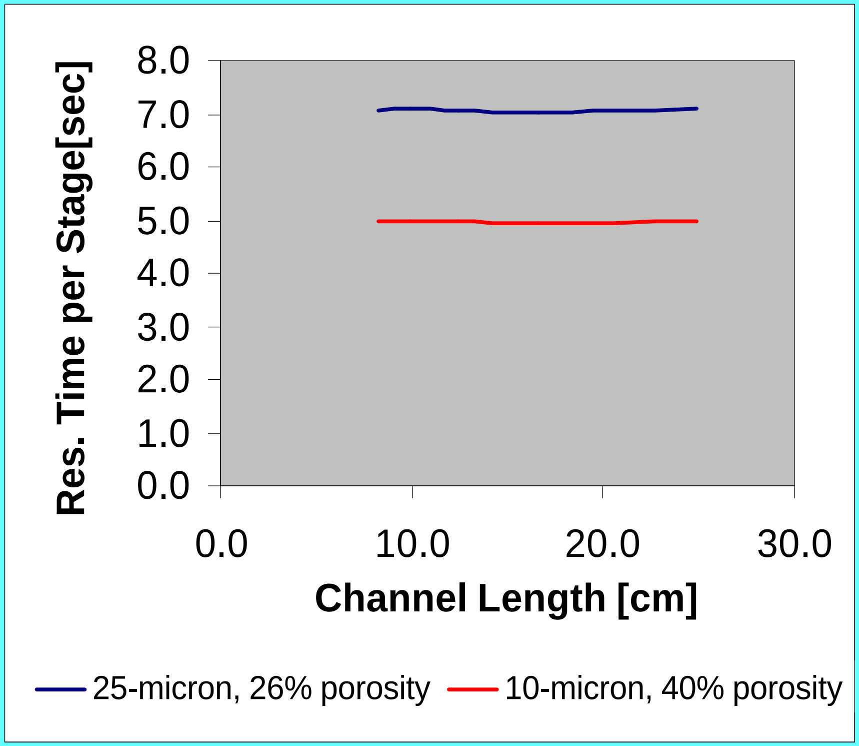
- Design Objectives - Counter-Current Continuous Process
  - Achieve a given number of theoretical stages
  - Minimize size -- Residence time / Number of stages
  - ΔP Constraint to prevent breakthrough

- Test-case - Acetone Extraction from Water Using 1,1,2-TCA
  - Equilibrium distribution coefficient, $m_s = C_S/C_R = 2.1$
  - Solvent to feed flow ratio, $Q_S/Q_F = 0.475$
  - Two contactors
    - 25-micron thick, 26% porosity
    - 10-micron thick, 40% porosity

STEP 1
Locate Design Point to Accomplish Separation

Constant ΔP = 2 inches W.C.
Constant channel height = 100 microns
Vary flow rate and channel length inverse proportionally





Battelle

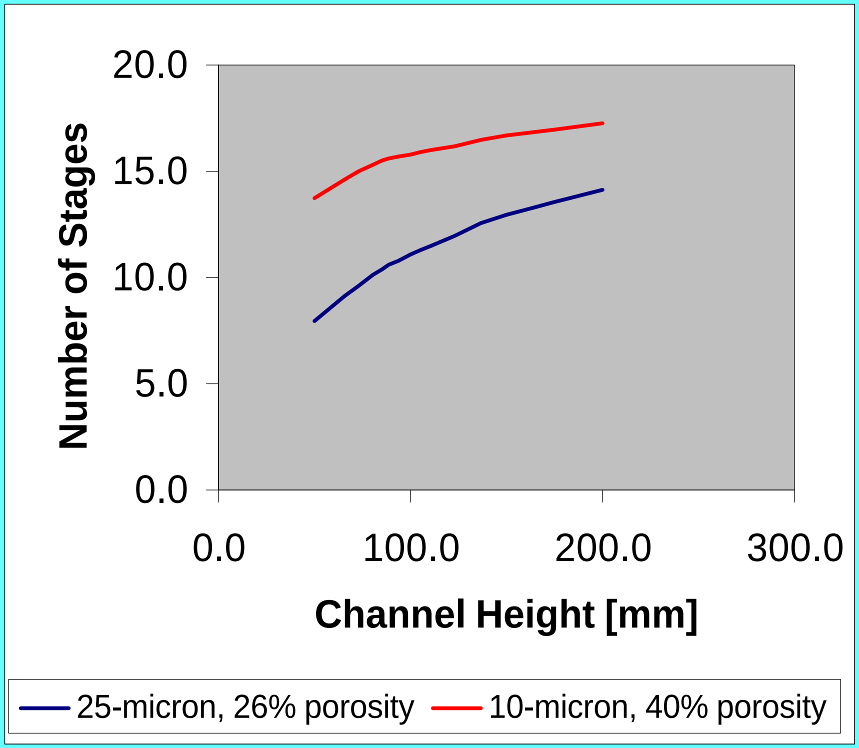
U.S. Department of Energy
Pacific Northwest National Laboratory

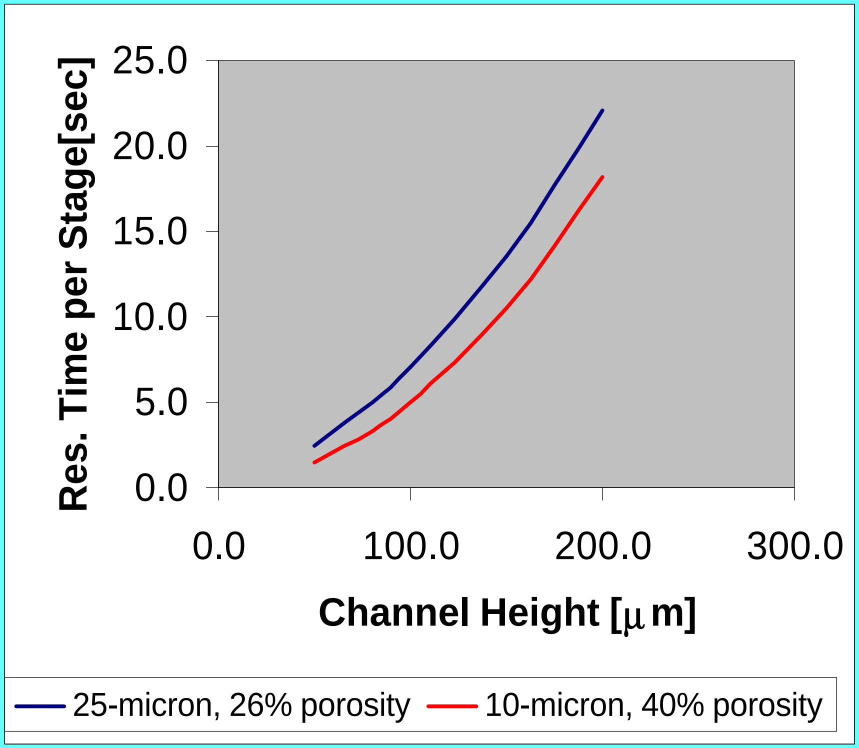
STEP 2
Miniaturize Architecture

Constant ΔP = 2 inches W.C.

Constant Peclet Number

Vary channel height, square root of length, and flow rate proportionally





How Small?

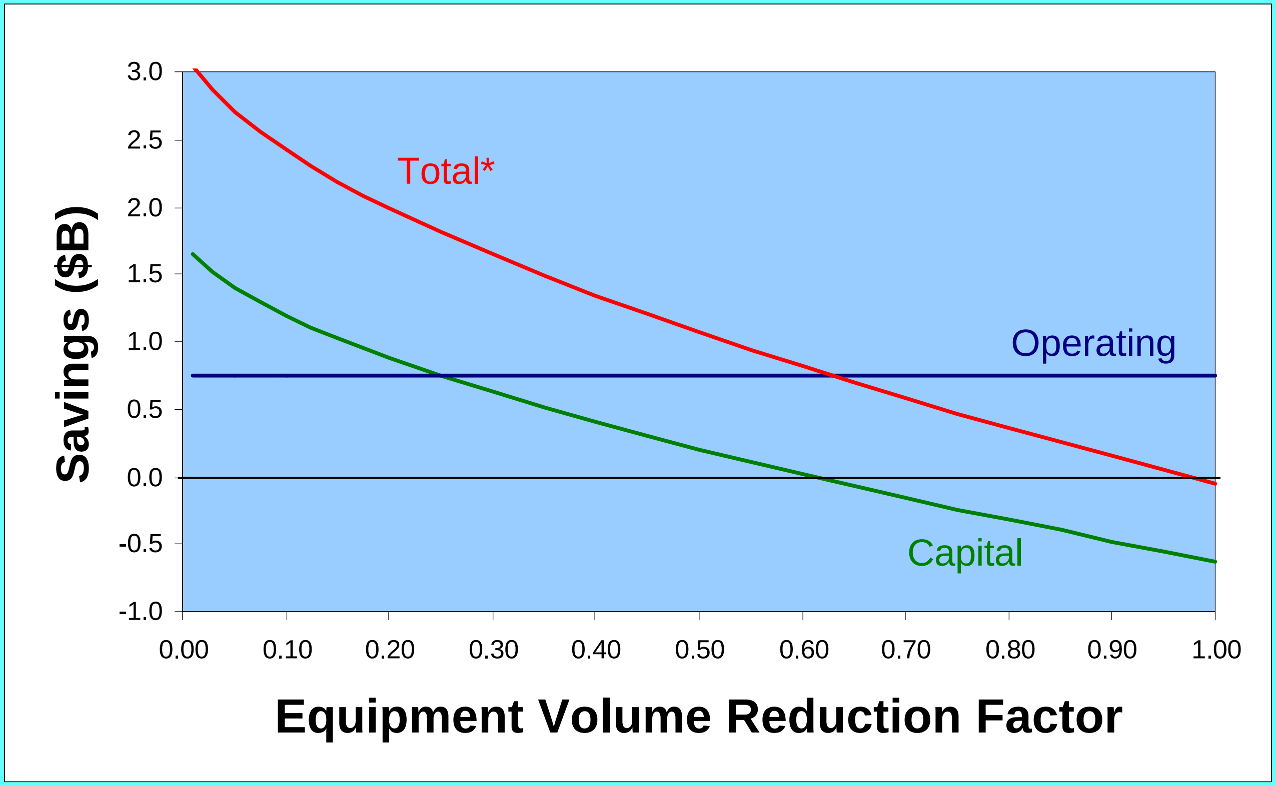
- Progress Toward 1 Second Residence Times per Theoretical Stage
- Acetone Extraction Using 1,1,2-TCA or Toluene:

	Capacity	HETP	T_{res}/Stage
	[$cm^3/cm^2/s$]	[cm]	[sec]
Sieve Trays	1	100-250	100-250
Structured Packings	0.8-5	20-180	10-80
Microchannels	0.2	0.25-5	1-20

- Order of Magnitude or More Reduction in Hardware Volume

Hanford Tank Remediation System Study:
Process Intensification with Process Miniaturization

Cost Savings Relative to TWRS Baseline



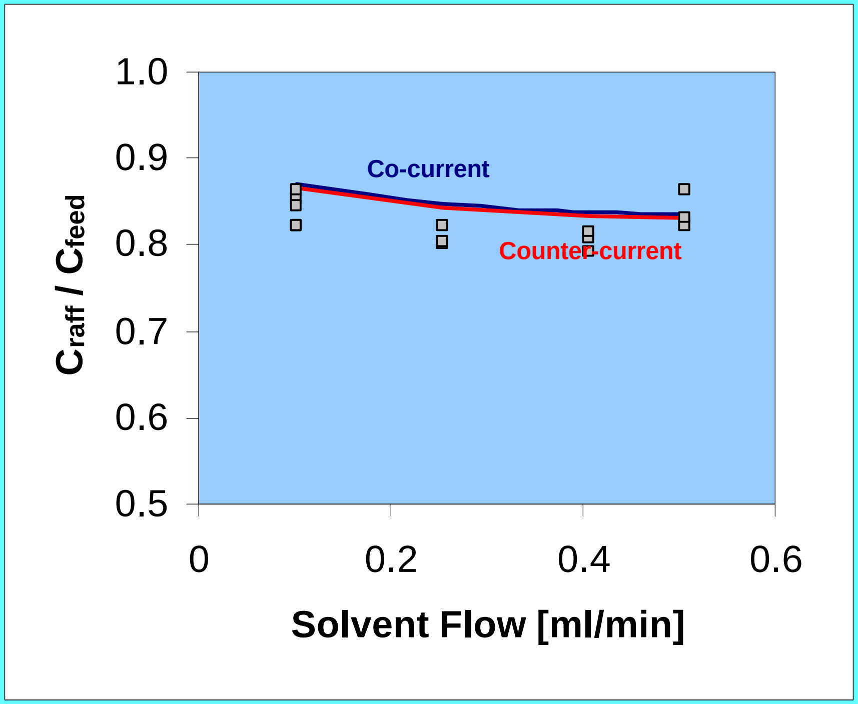
* Total Costs not sum of Operating and Capital; includes fixed and decontamination

Battelle

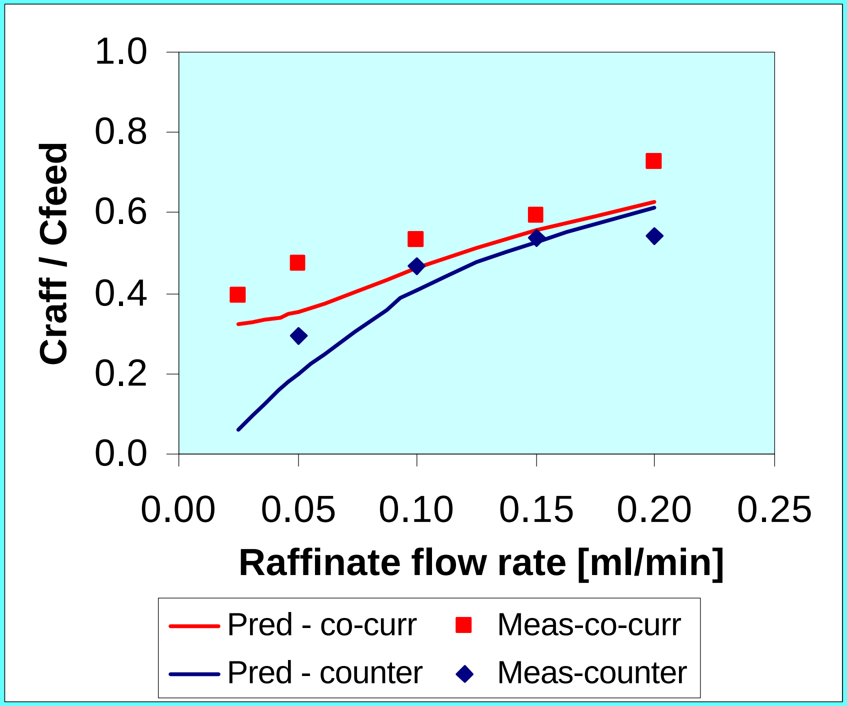
U.S. Department of Energy
Pacific Northwest National Laboratory

Solvent Extraction

Counter-current
Cyclohexanol extraction from water
Cyclohexane solvent
250-micron channels, 180-micron contactor
Constant feed residence time of 24 seconds

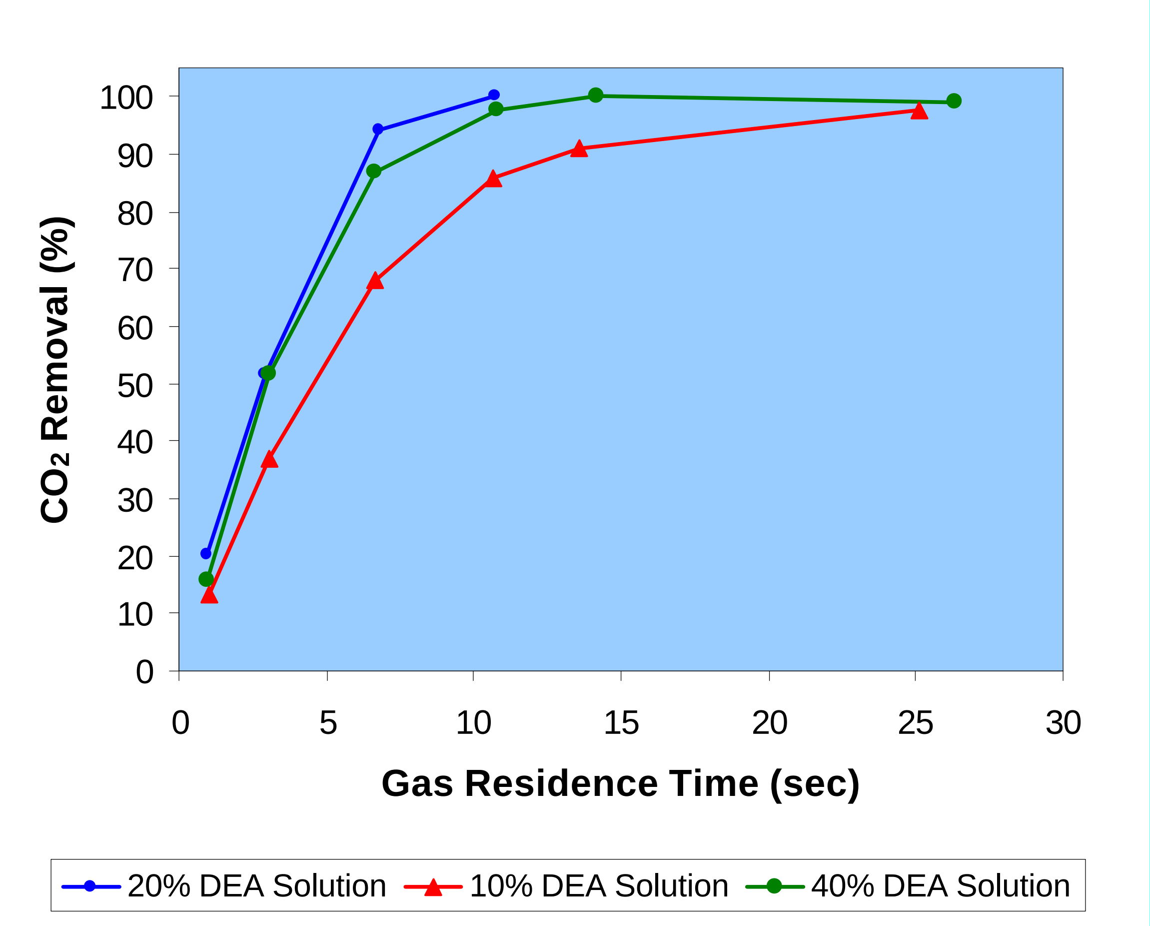


Counter-current
Acetone extraction from water
1,1,2-trichloroethane solvent
240-micron channels, 180-micron contactor
Solvent and raffinate at equal flow rates



Gas Absorption

CO_2 Absorption with DEA Solvent



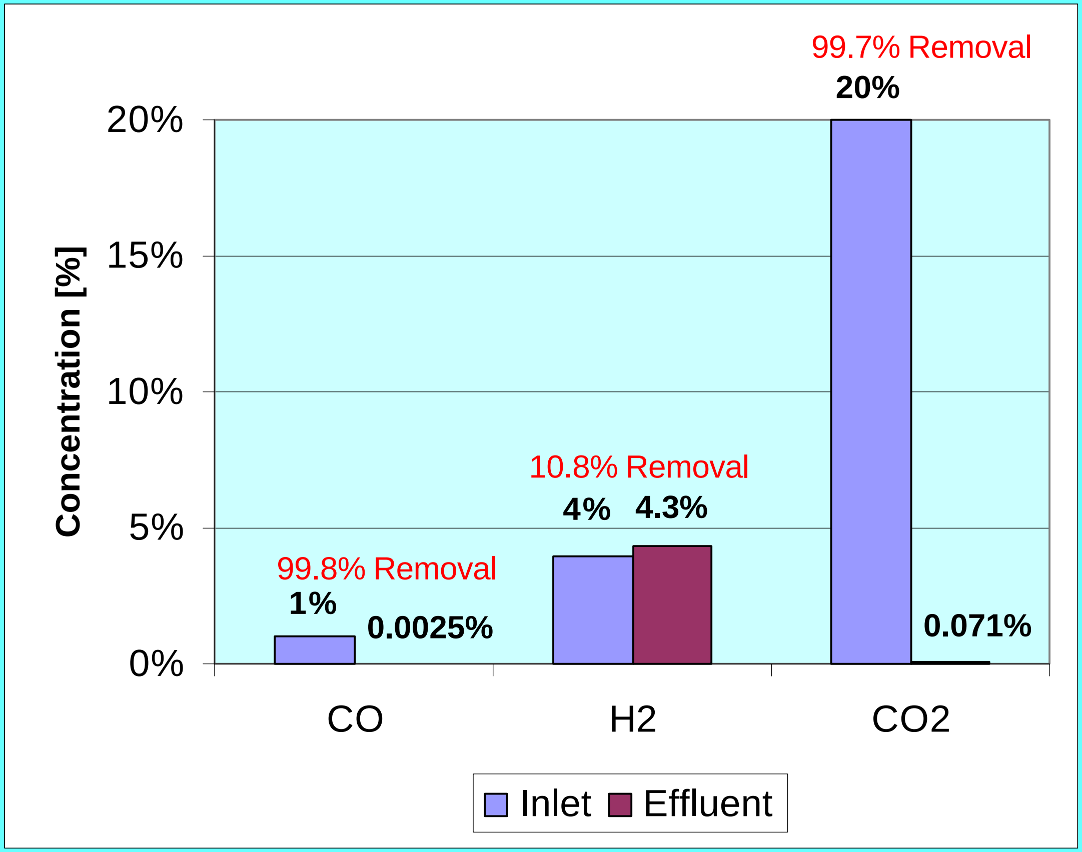
Cocurrent flow through 400-micron channels at 26 sec solvent residence time

- DEA solvent
- 25% CO_2 and 75% N_2
- Applications:
  - NASA Mars ISRU
  - Carbon management

Gas Absorption

CO Absorption with Copper Ammonia Formate Solvent

Gas residence time = 1.3 sec



Countercurrent flow through 250-micron channels at 36 sec solvent residence time with Teflon membrane

- Copper Ammonia Formate
- 1%CO, % H_2, 20% CO_2, 75% N_2
- Application:
  - Fuel cell feed gas clean-up

Battelle

U.S. Department of Energy
Pacific Northwest National Laboratory

Summary

- Residence time per theoretical stage is approaching 1 second for chemical separations.
- Microchannel devices have potential for orders of magnitude reduction in hardware volume over conventional technology.
- Microchannel based separations are penetrating markets where size and weight matter.