Microtechnology –New Paradigm For Process industries

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In Affiliation With

MBI

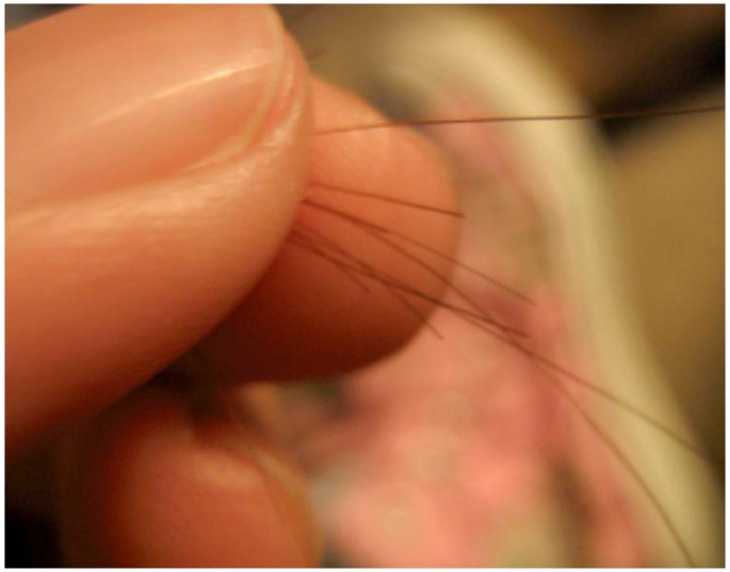
Microproducts Breakthrough Institute

ONAMI

Oregon Nanoscience And Microtechnologies Institute

Microtechnology

The study, development, and application of devices whose operation is based on the scale of 1-100 microns.

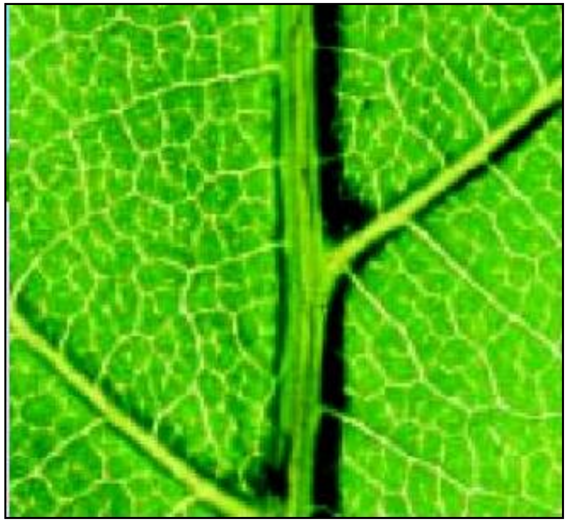


(A human hair is approximately 100 microns thick.

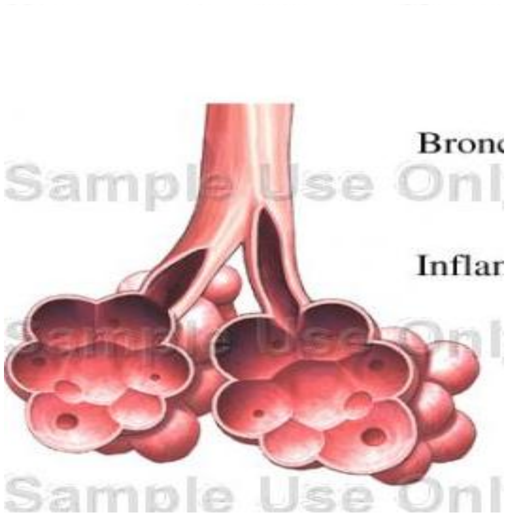
Image source: http://www.flickr.com/photos/thestarshine/69591402/

Nature’s Microtechnology

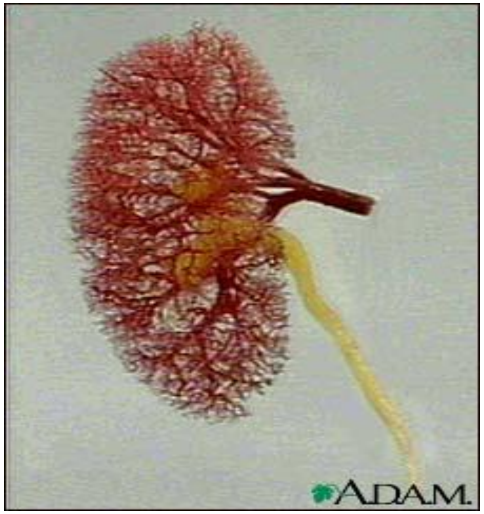
Nature has selected the micro scale for the realization of many biological processes.



Leaf



Alveoli



Kidney

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What is Microtechnology Good For?

- Production of information
  - lab-on-chip
- Production of services
  - pacemaker
  - kidney dialyser
- Production of energy and bulk material
  - chemicals
  - fuels
  - nanoparticles

Micro/Nano Technologies Under Development In Dr. Jovanovic Laboratory

- **Microreactors for Biodiesel Production.**
- **Microreactors for Production H_2O_2.**
- **Microreactor for Desulphurization of Fuels.**
- **Microseparators for Liquid-Liquid Extraction.**
- **Microreactors for Production of Veins and Arteries.**
- **Micro Haemo Dialyser.**
- **Microreactor for Destruction of Toxic Waste.**
- **Microseparators for Desalination of Water**
- **Microreactors for Steam Reforming (atm, 1100^{o}C)**

Fundamental Advantages of Microtechnology

- **Intensification of Heat and Mass Transport**
  - Small scale - Short time of mass and heat transport (| $=l^2/D$)
- **Reduced Size**
  - 10-100 times reduction in hardware volume over conventional technology;
  - 5-50 times reduction in hardware mass;
  - Shifts size-energy trade-offs toward higher efficiency;
  - Able to integrate heat exchanges with reactors and separators simplifying processes.
- **Large surface to volume ratio (10^5-10^8 m^2/m^3)**
- **Changes chemical product distribution**

Fundamental Advantages of Microtechnology

- **Low Pressure Drop**

  Reduces power for pumps, fans, and blowers;
- **Gravity independence**

  Gravity effect diminish to surface and hydrodynamics forces as size of channels decreases;
- **High Degree of Reaction Control**

  Minimizing unwanted environmental and side reactions;
  Minimize unwanted reversible reactions;
  Enables processing of very energetic reactants;
  Intensification of chemical kinetics (*the last frontier in mass transport*)
- **Extremely High Quench Rates**

  Small reactant volumes mean less mass or energy required to quench;
  Extremely rapid heat transport enables fast thermal discharge.

Advantages of Microtechnology-Parallel Architecture

- **Fast screening of materials, catalyst and processes**
- **Flexibility in capacity and in design**

  - Provides for deployment at wide range of scales;
  - Facilitates gradual expansion of capacity as scale of operations grows by adding more modules;

- **Operating robustness and controllability**

  - Enhances reliability, allowing problems to be isolated and repaired.

- **Mass Production of Microscale Components**

  - Microlamination process enables mass production;
  - Bonded stacks can contain multiple processes;
  - Multiple processes in a single device reduces field assembly and testing.

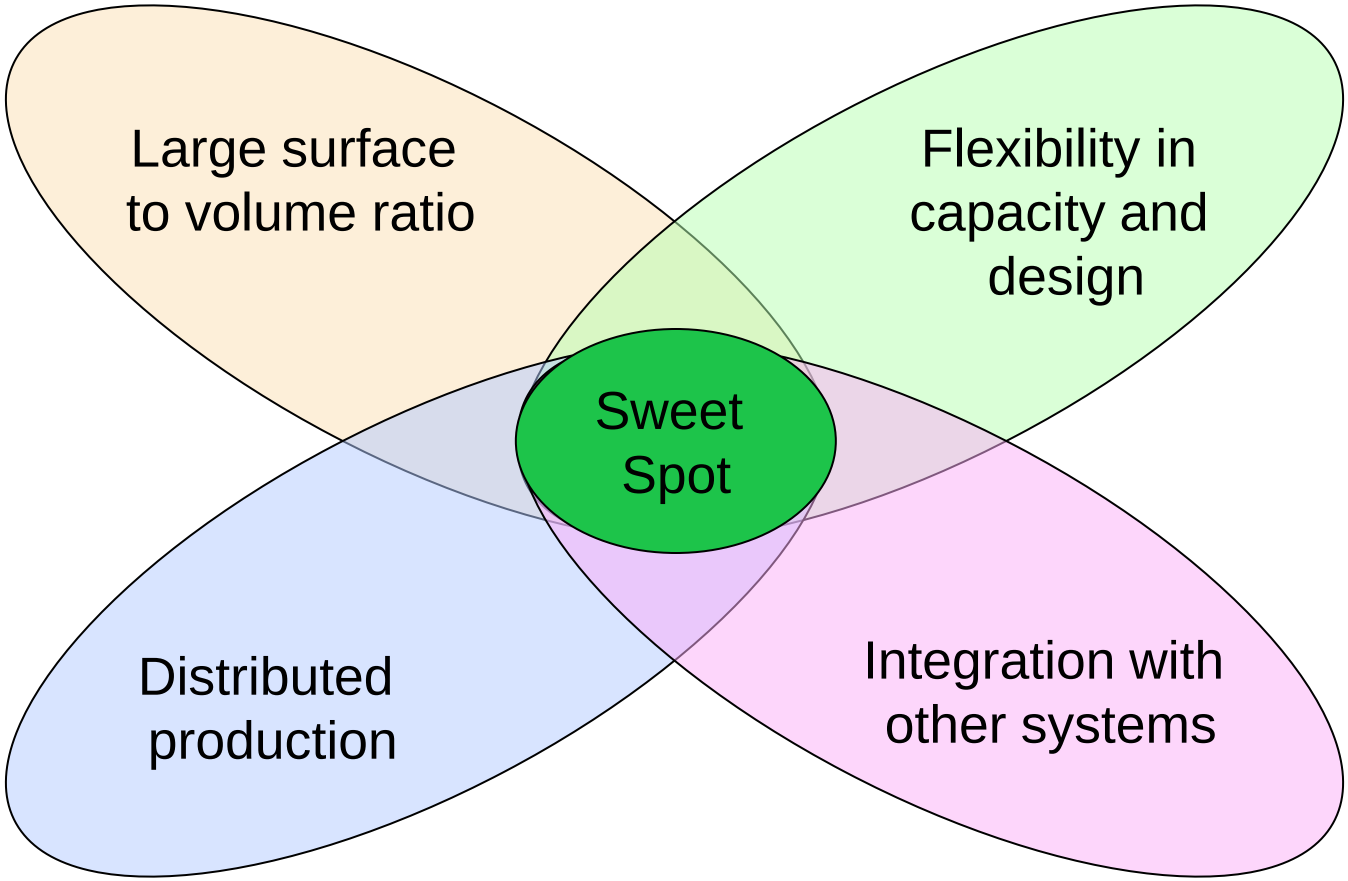
Commercial Advantages of Microtechnology

- **Lower capital investment;**
- **Lower operating cost;**
- **Faster transfer of research to commercial production;**
- **Earlier start of production at lower cost**
  - Reduces life-cycle costs through early testing at implementation scale;
- **Easier scale up (numbering -up) to production capacity;**
- **Distributed technology implementation** (distributed production);
- **Integration of micro-technologies with other systems;**
- **Lower cost of transportation of material and energy;**
- **Replacing batch with continuous processes.**

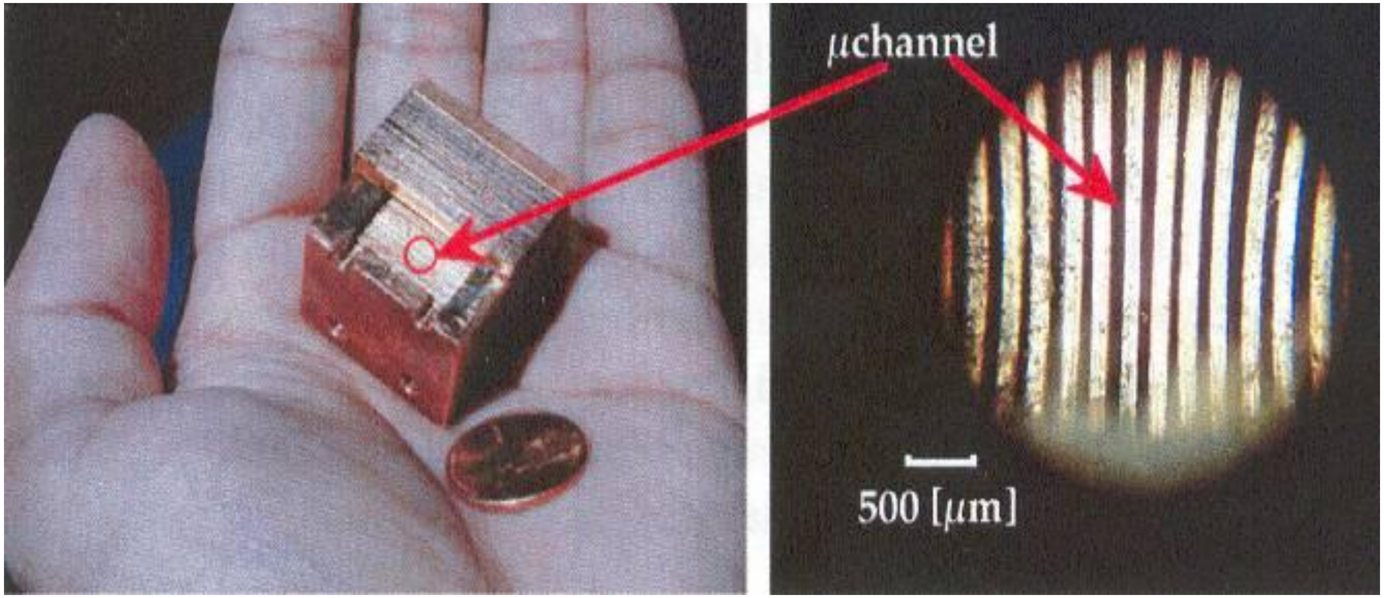
Safety and Security Advantages

- **Small channel inhibits flame/explosion front propagation;**
- **Small volumes translate to low stored energy;**
- **Smaller volume less hazardous materials in the process.**

Sweet Spot of Microtechnology

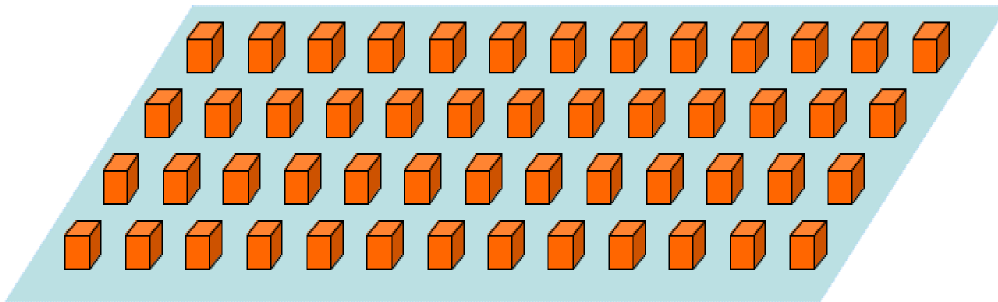


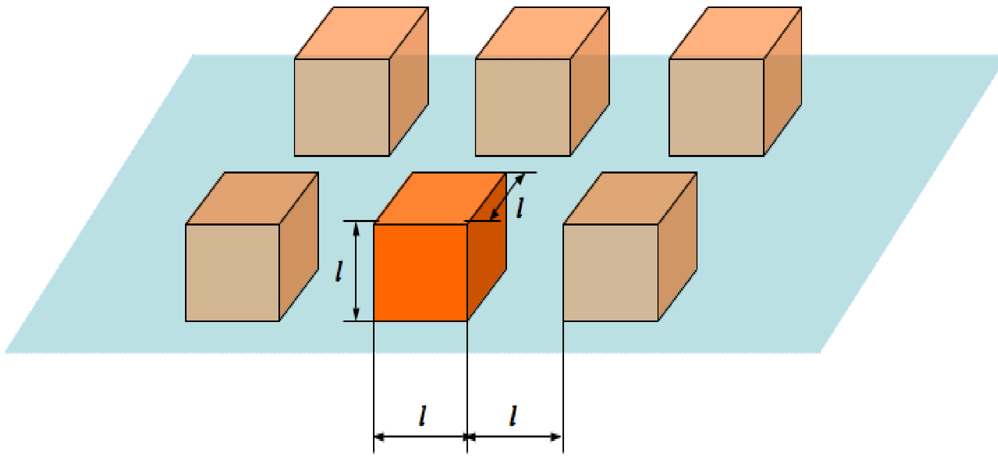
Micro-Scale Reactors



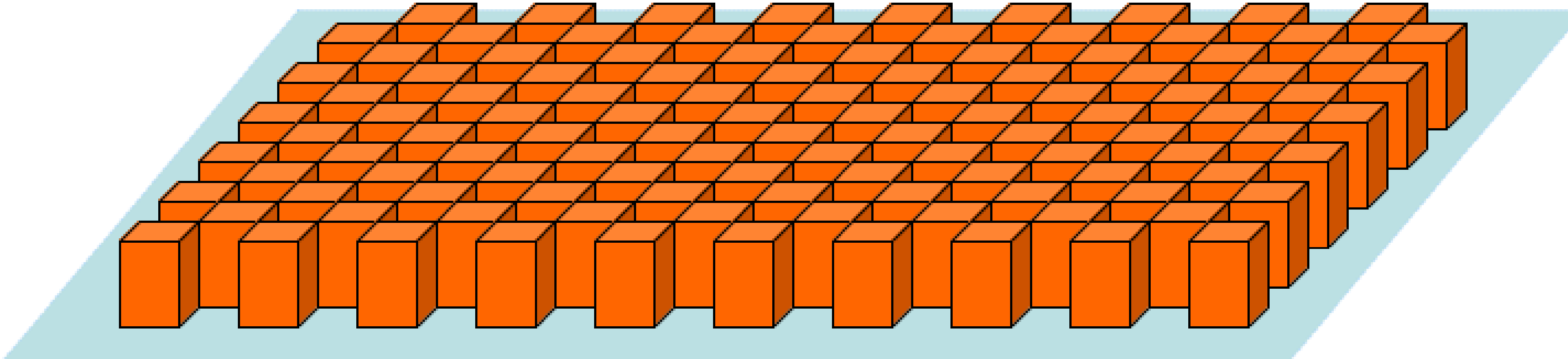
First MECS micro-reactor, OSU 1999

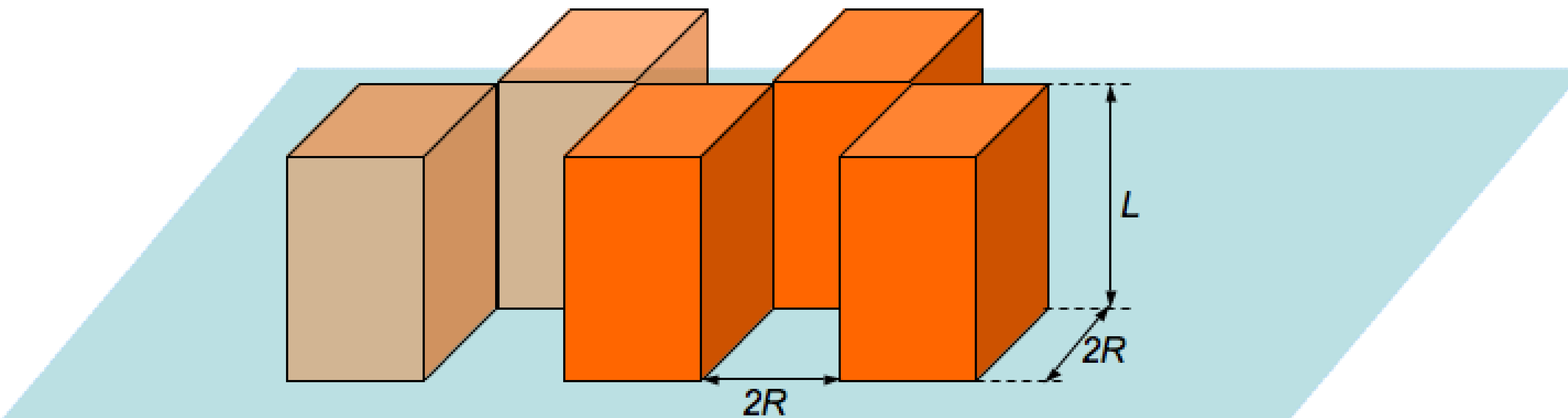
Catalyst and Catalyst Deposition



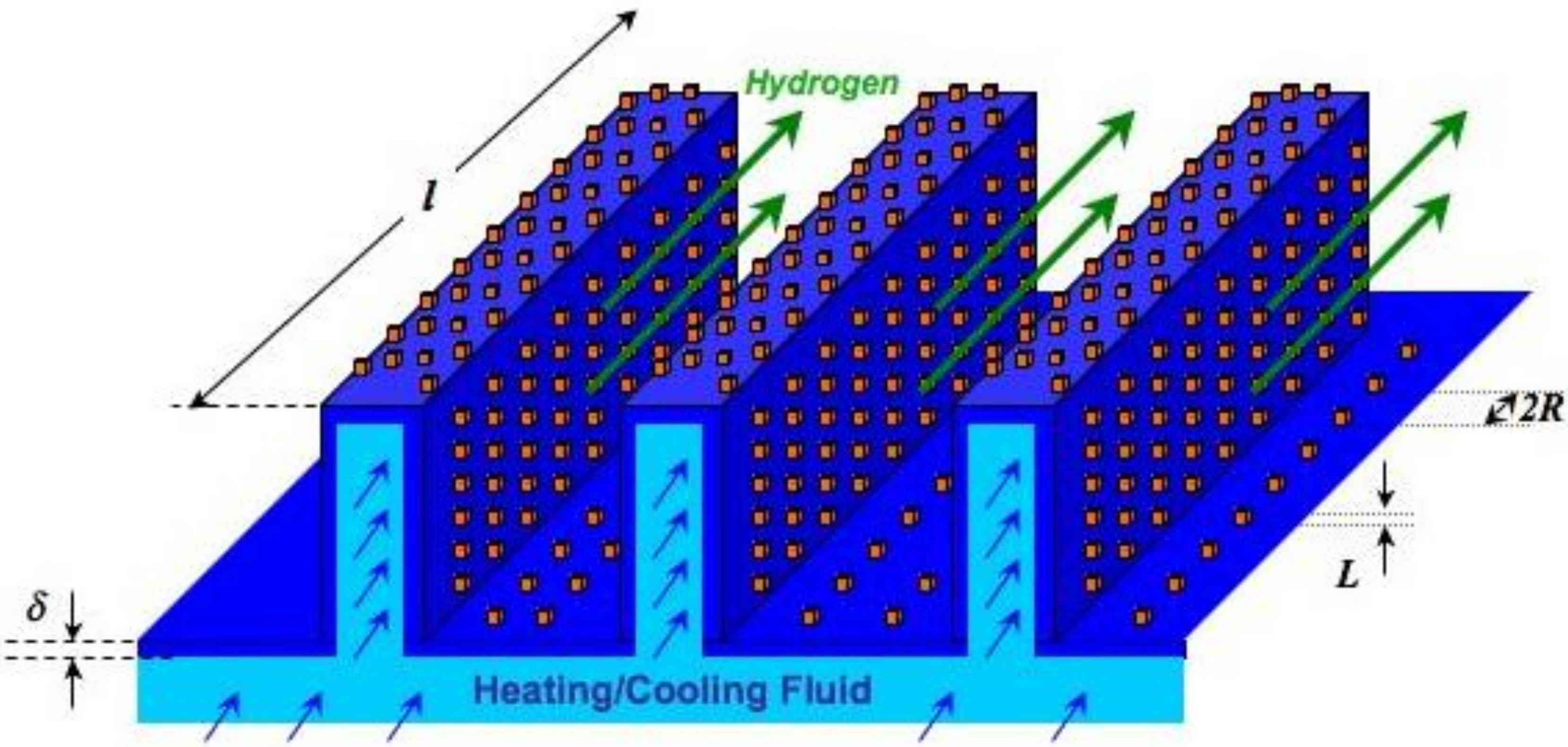


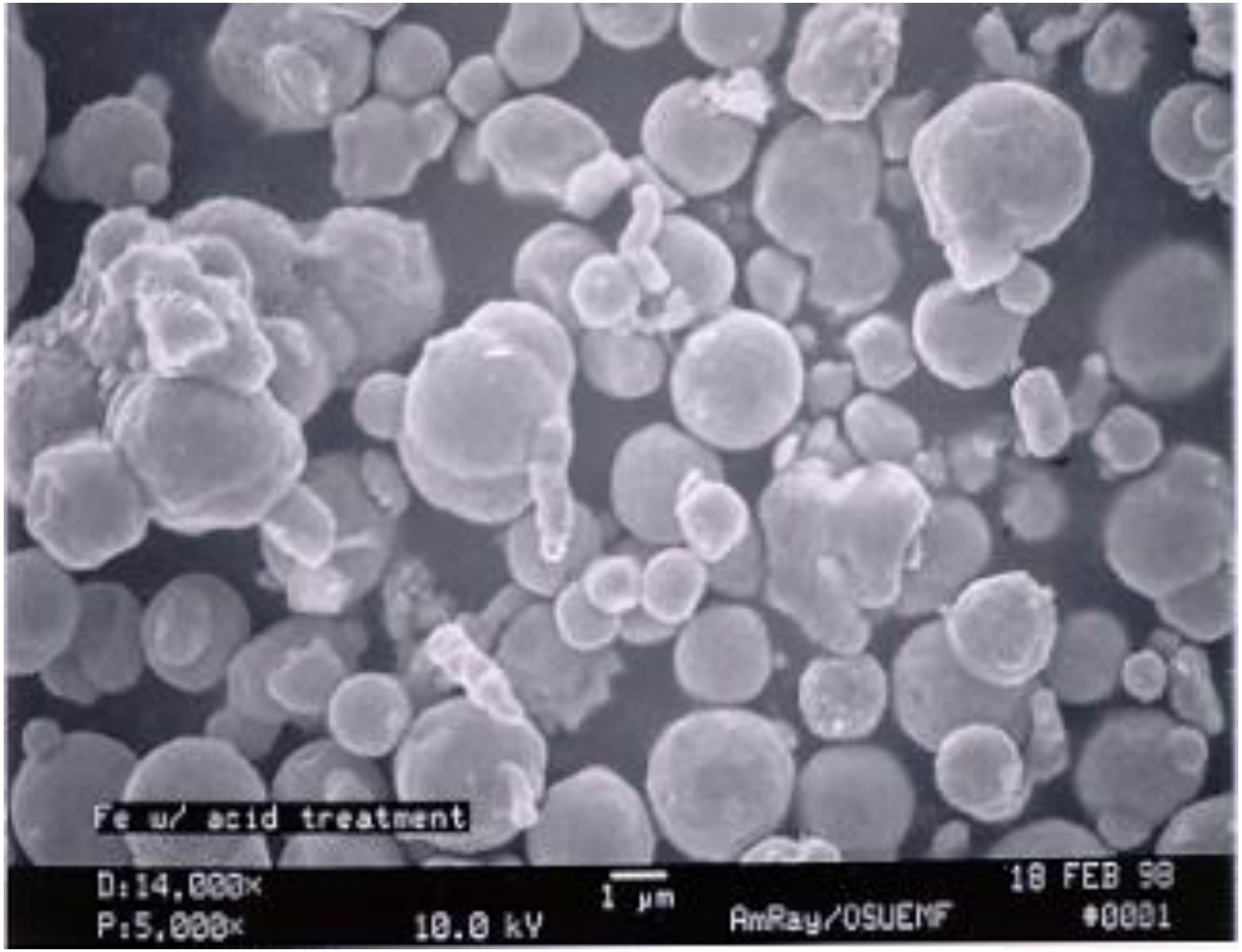
Catalyst and Catalyst Deposition



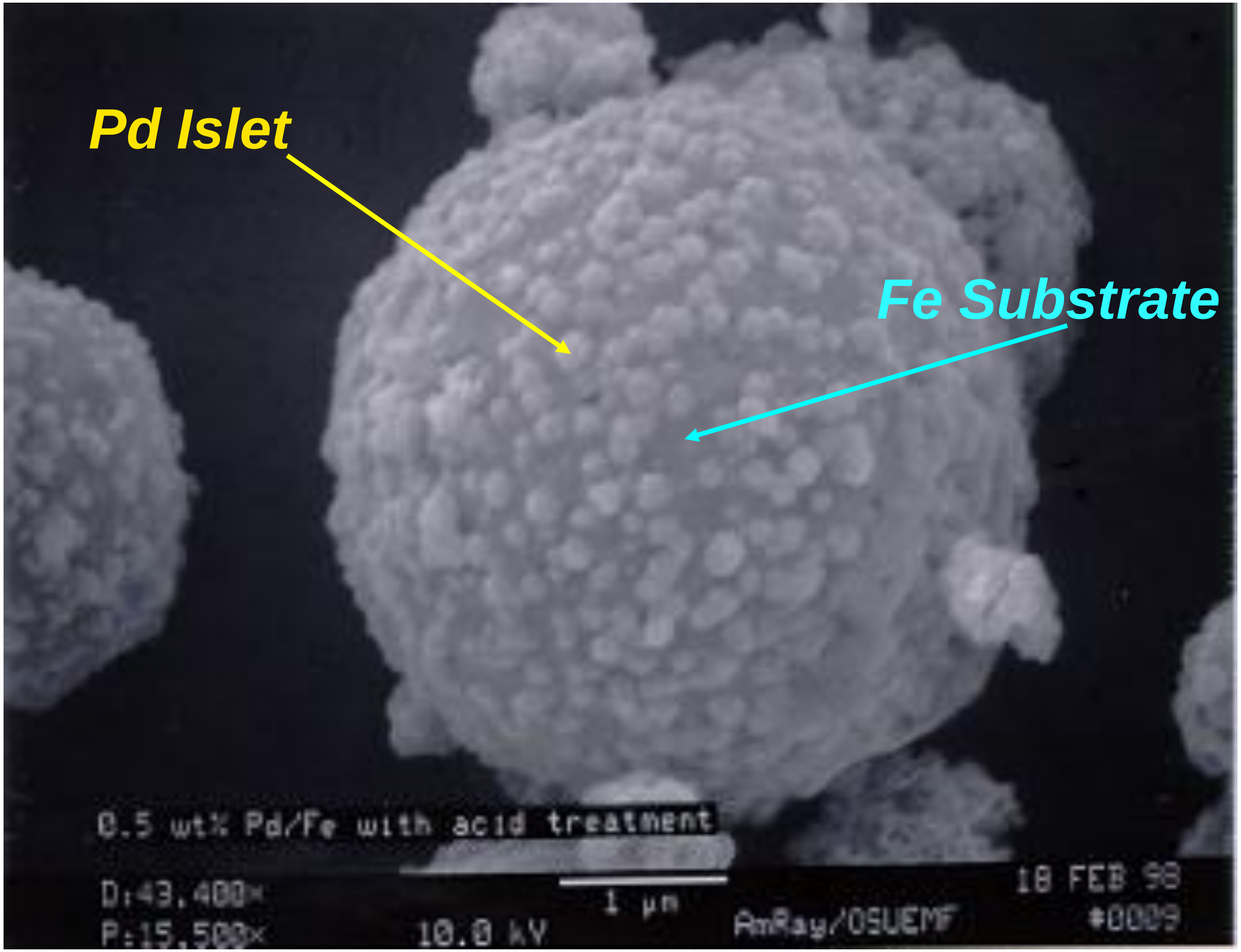


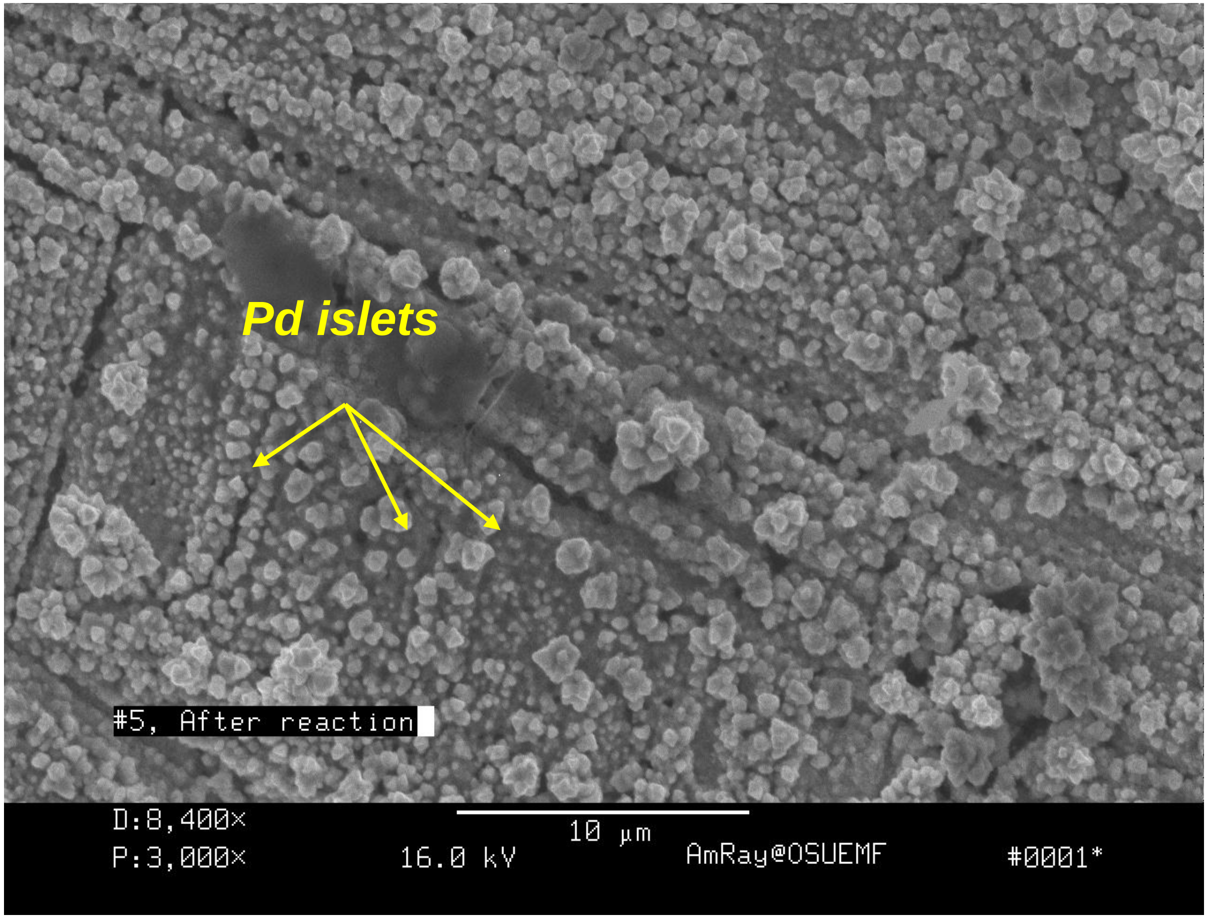
Catalyst and Catalyst Deposition



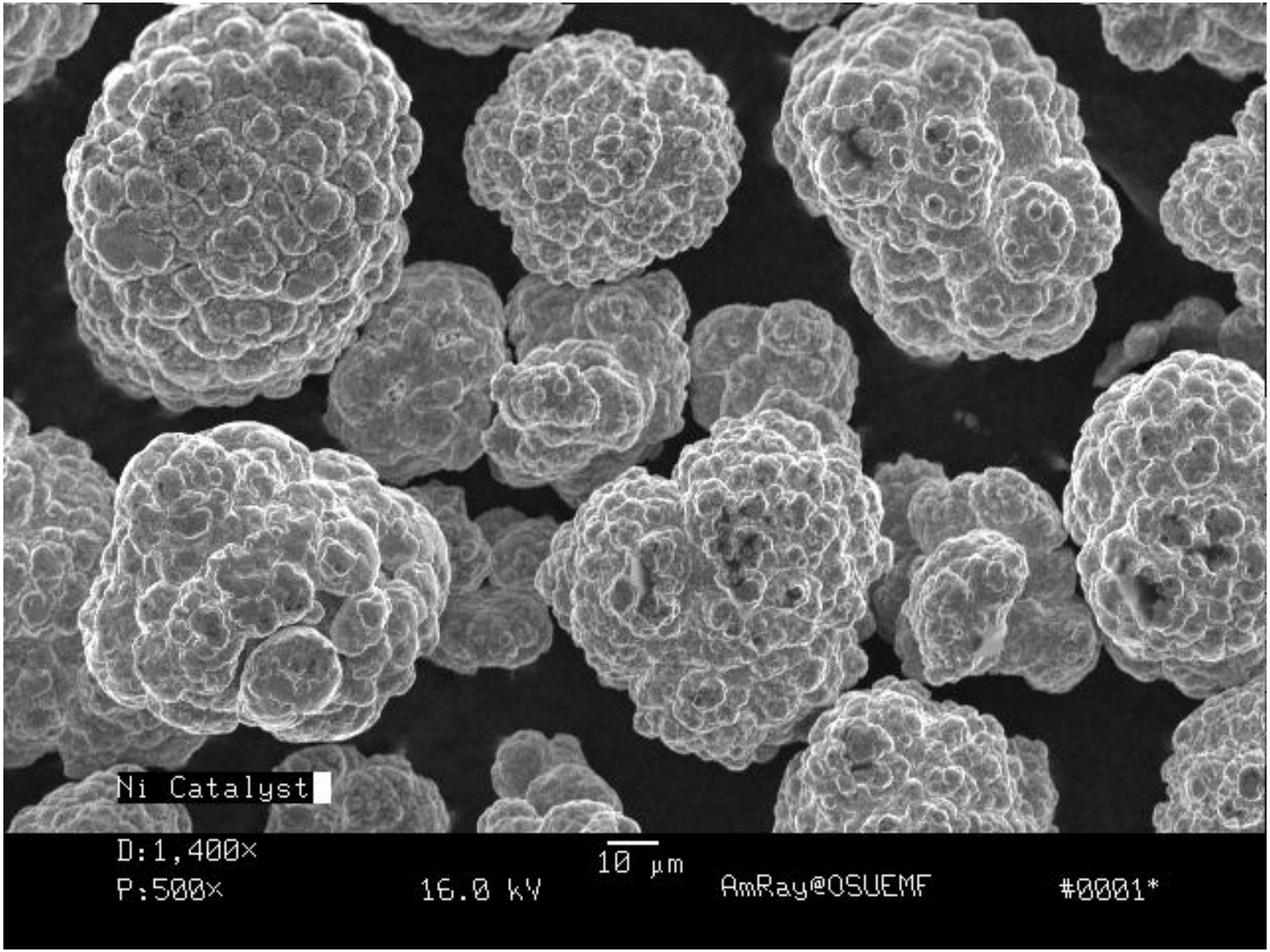

Fe w/ acid treatment
D:14,000×
P:5,000×
10.0 kV
1 μm
AmRay/OSUEMF
18 FEB 98
#0001

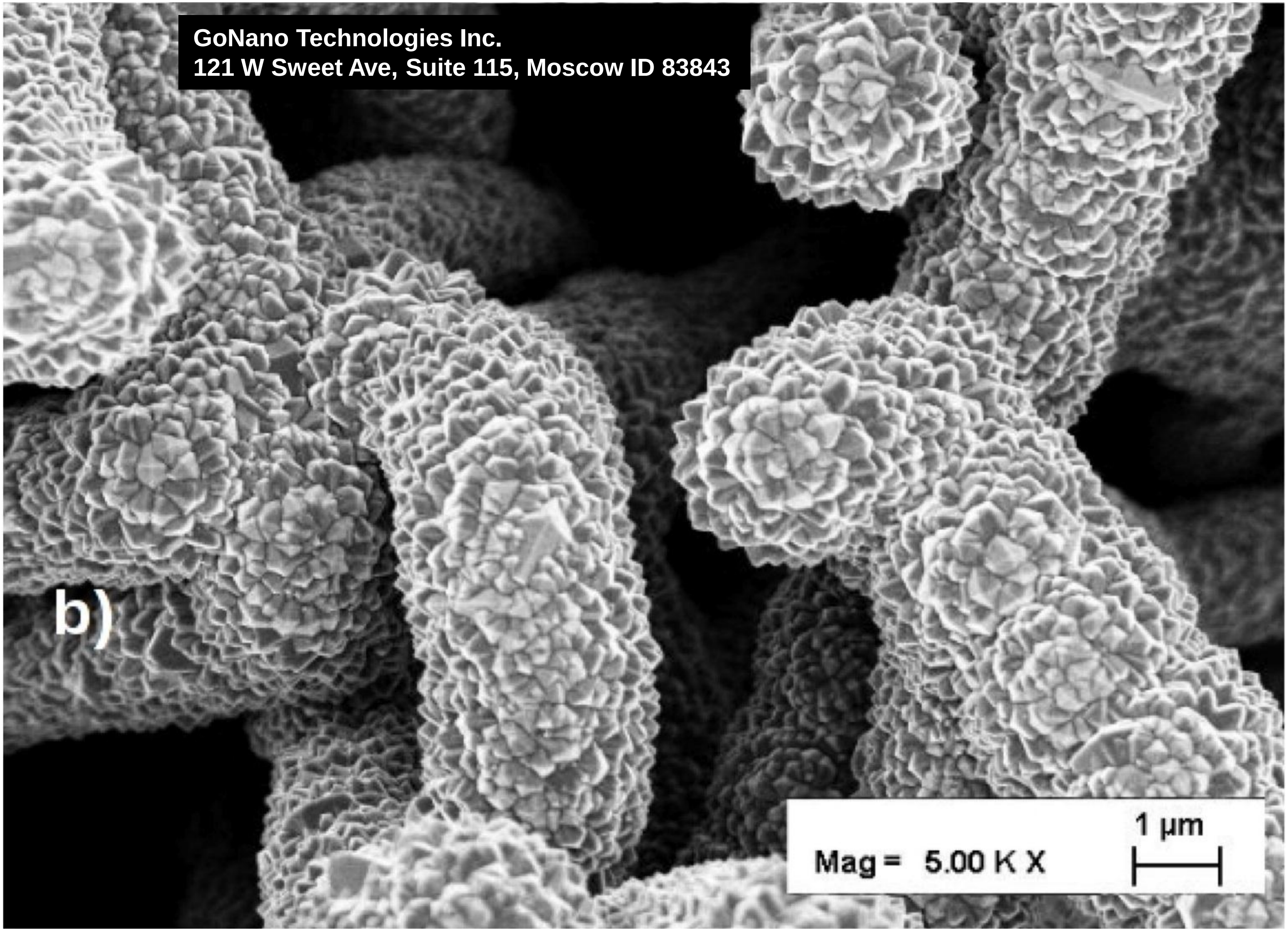

0.5wt% Pd/Fe w/acid treatment
D:14,000×
P:5,000×
10.0 kV
1 µm
AmRay/OSUEMF
18 FEB 98
#0003

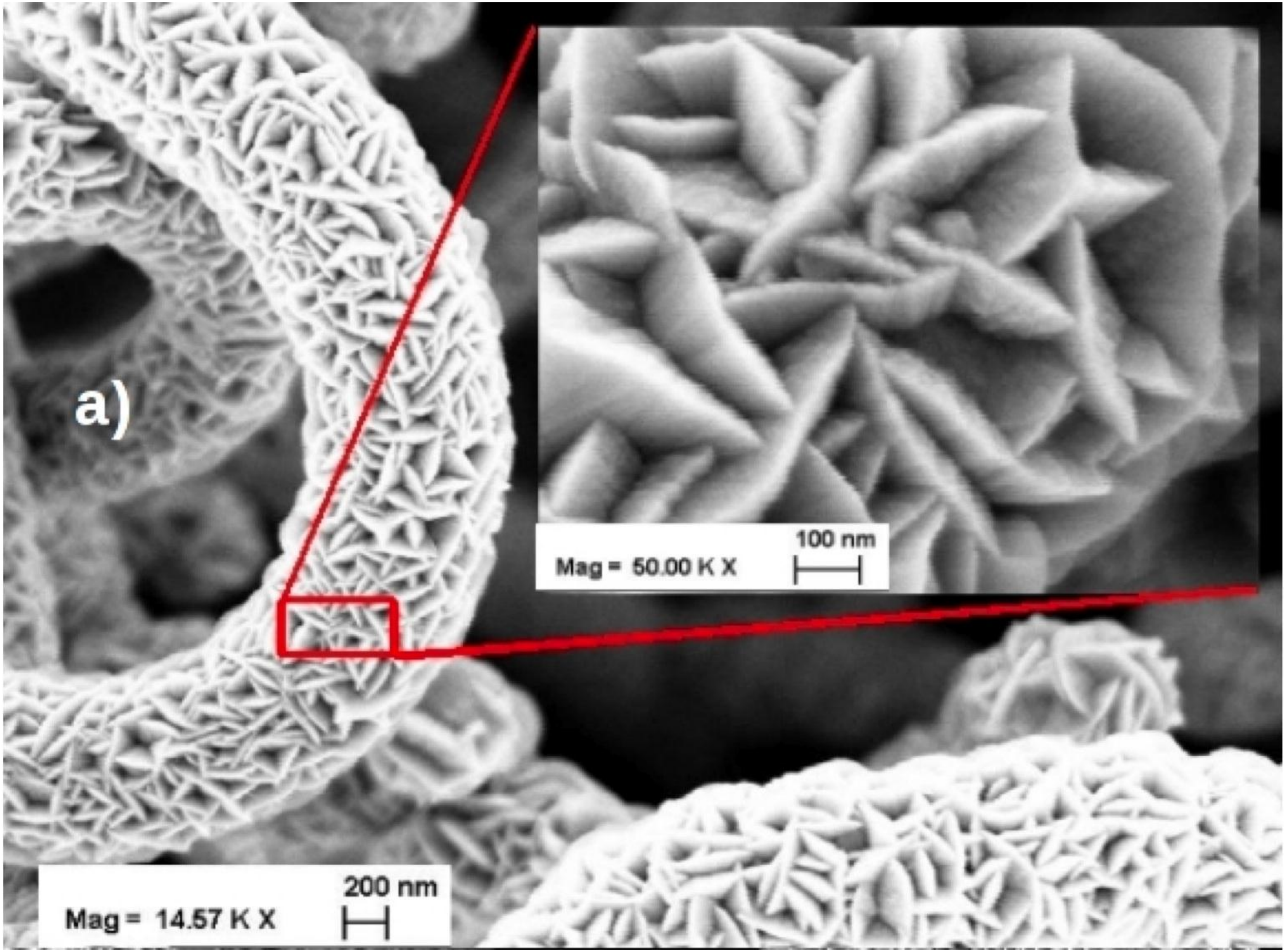

Pd Islet
Fe Substrate
0.5 wt% Pd/Fe with acid treatment
D:43,400×
P:15,500×
10.0 kV
1 μm
AmRay/OSUEMF
18 FEB 98
#0009



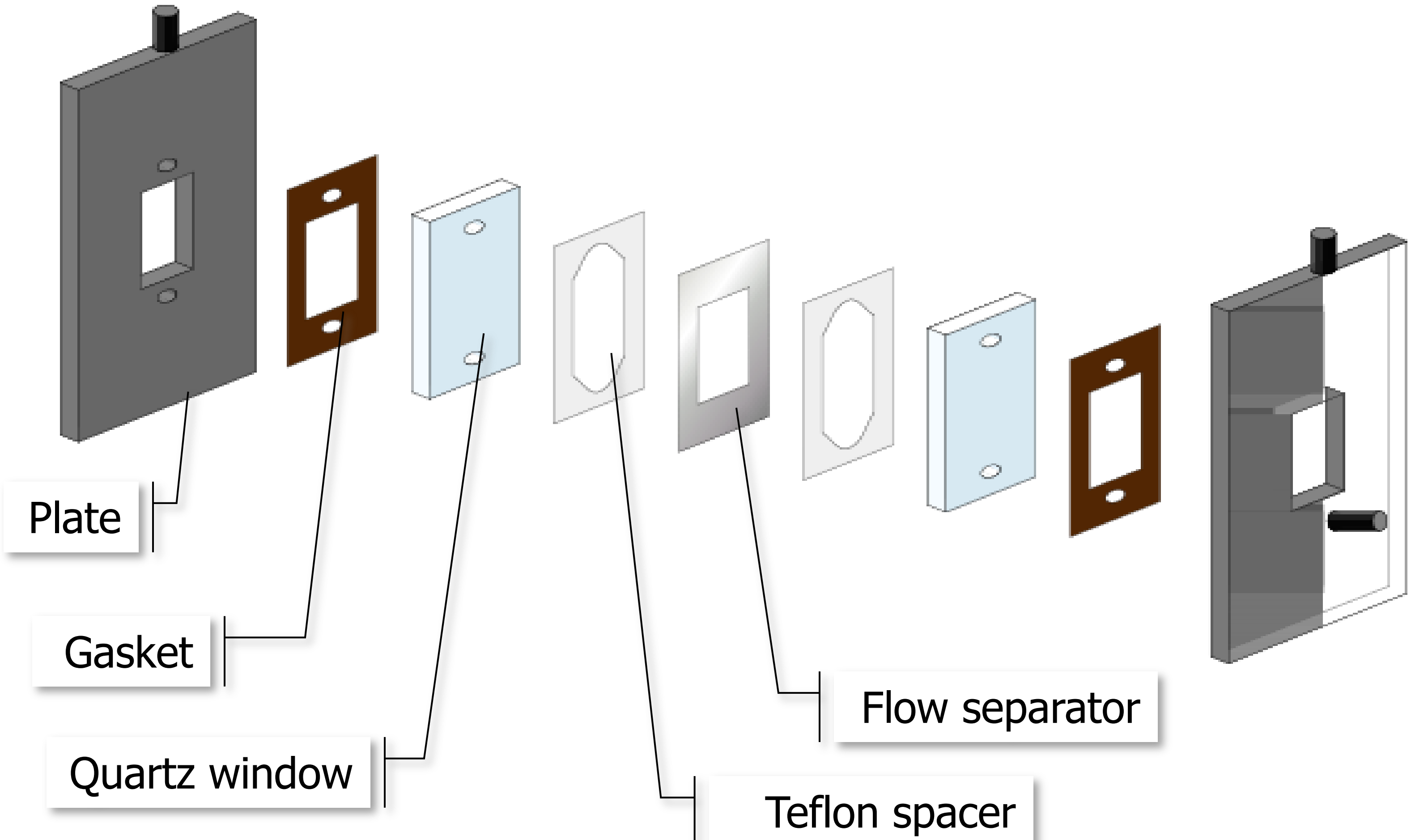
FeAl 200 µm thick sheet, operating temperature 1100 ^{o}C


Ni Catalyst
D:1,400×
P:500×
16.0 kV
10 µm
AmRay@OSUEMF
#0001*

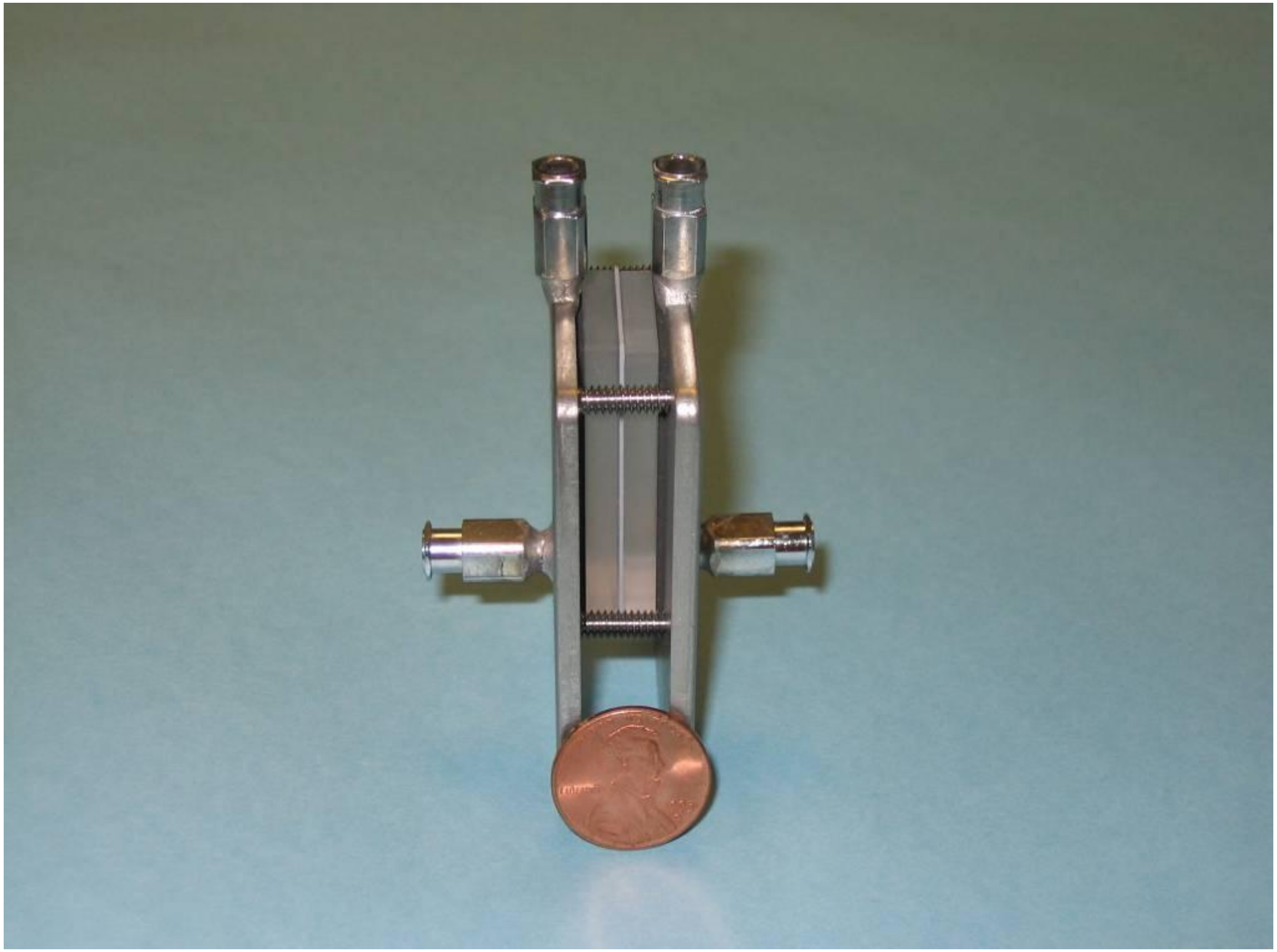

GoNano Technologies Inc.
121 W Sweet Ave, Suite 115, Moscow ID 83843
b)
1 μm
Mag = 5.00 K X


a)
100 nm
Mag = 50.00 K X
200 nm
Mag = 14.57 K X

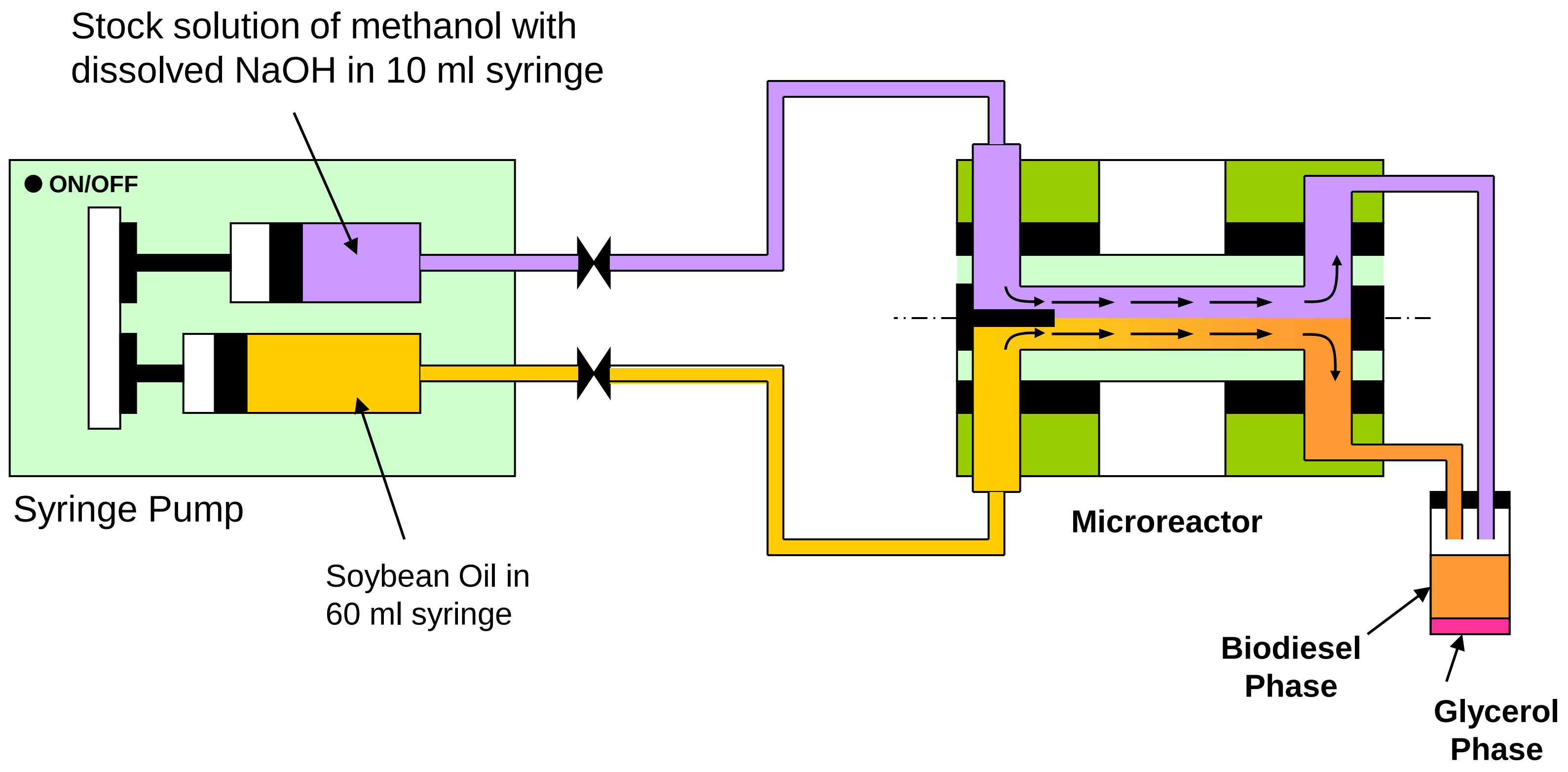
Microreactors



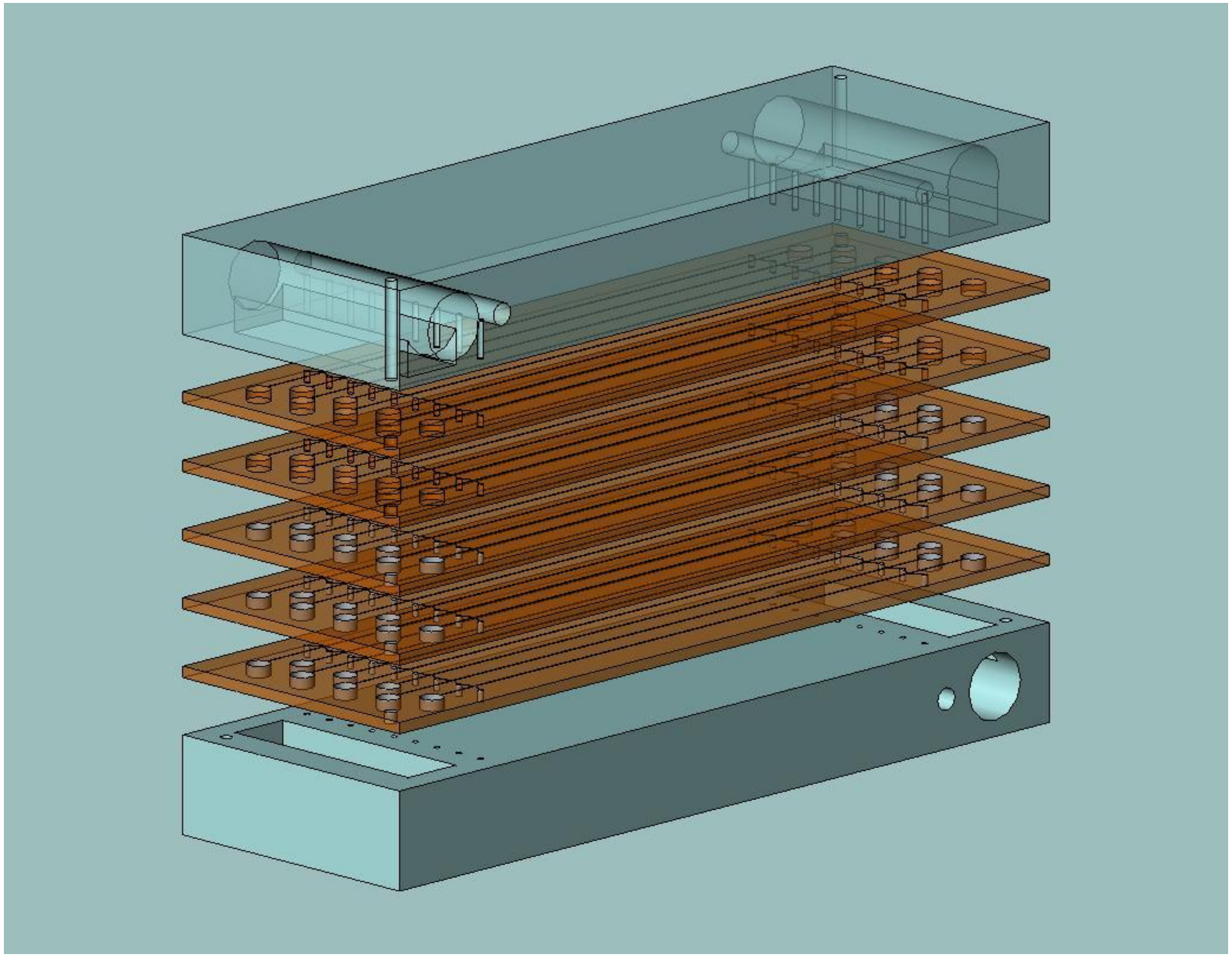
Microreactors

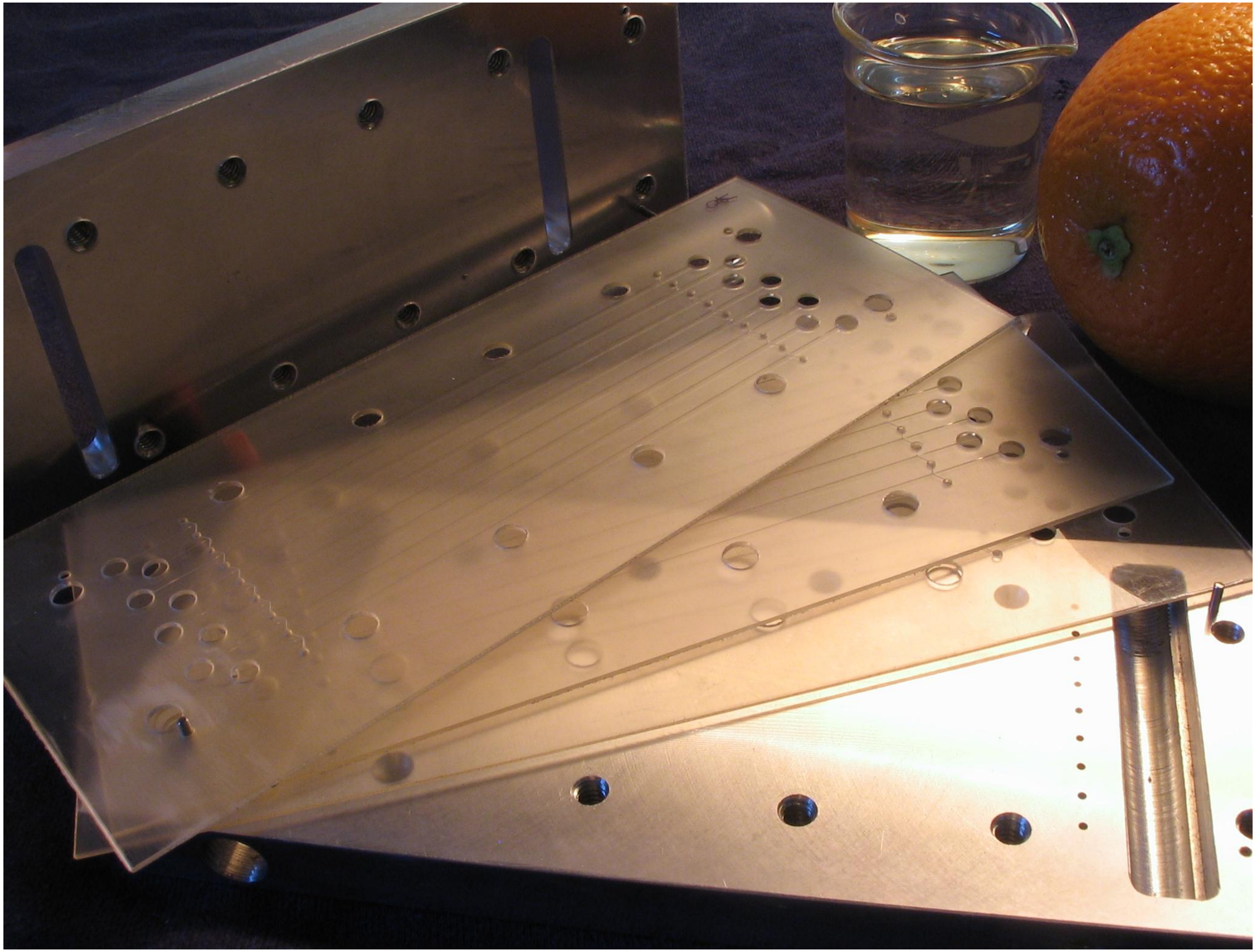


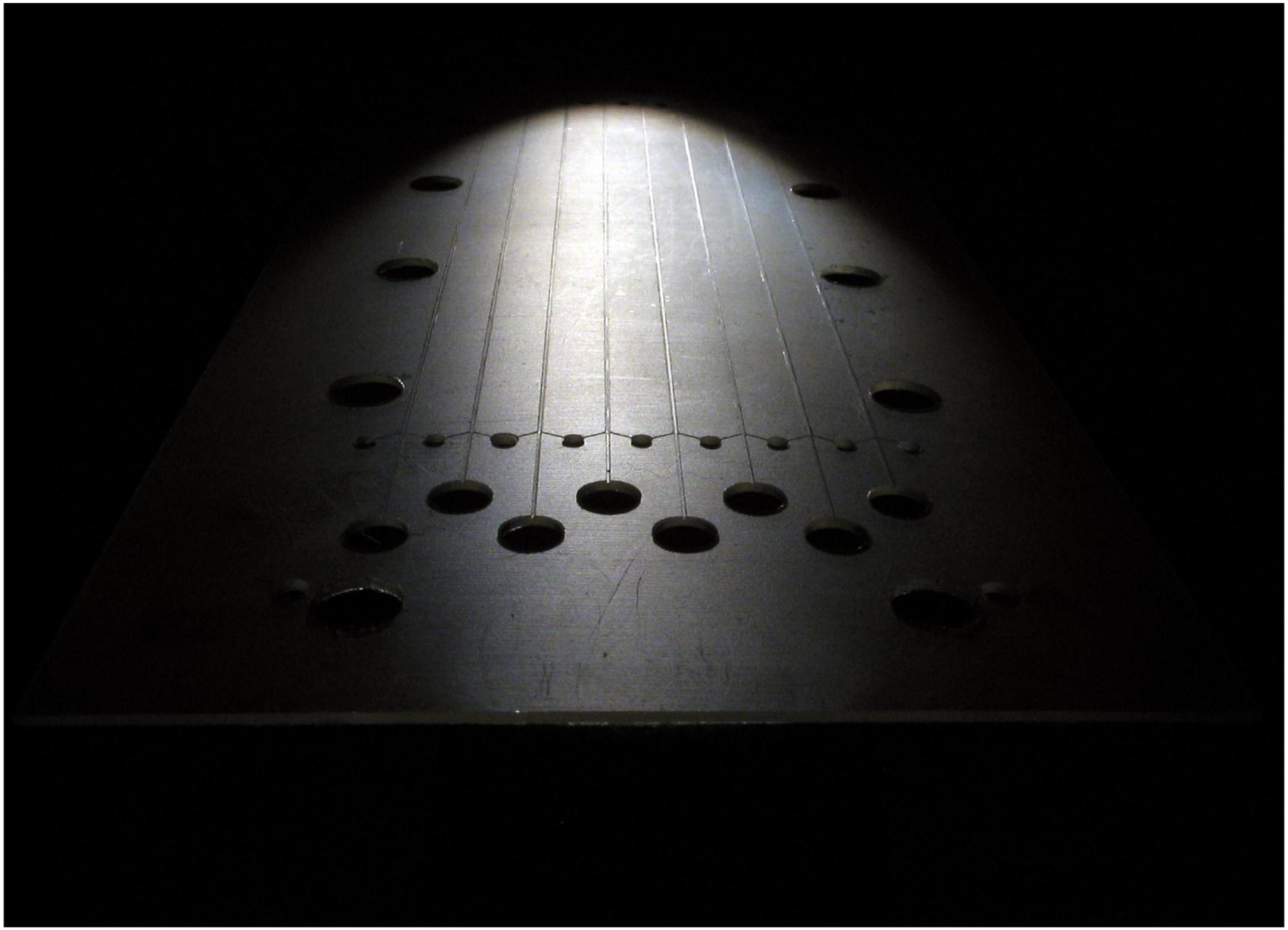
Experimental Setup – Biodiesel Production



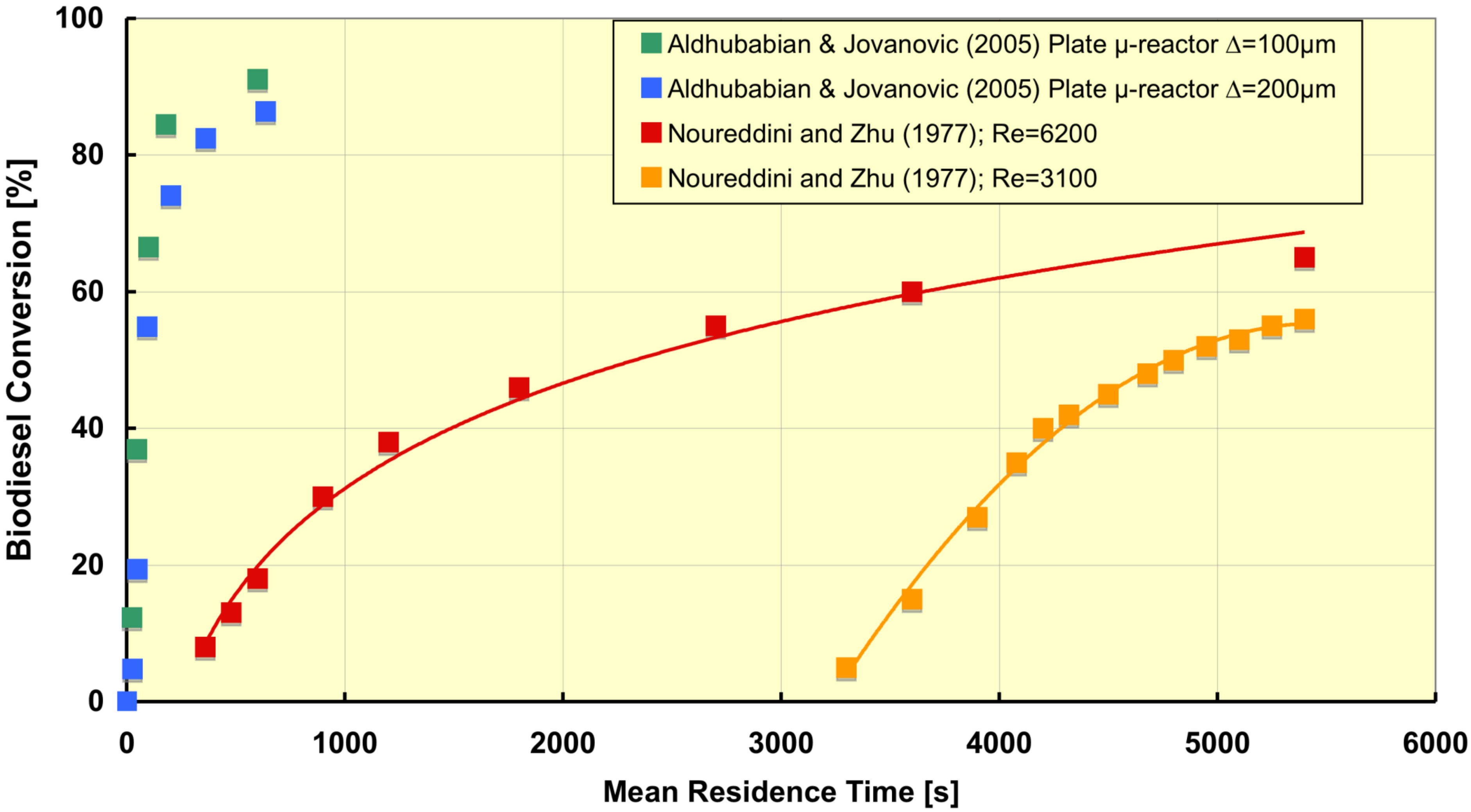
Scale-Up = Numbering-Up



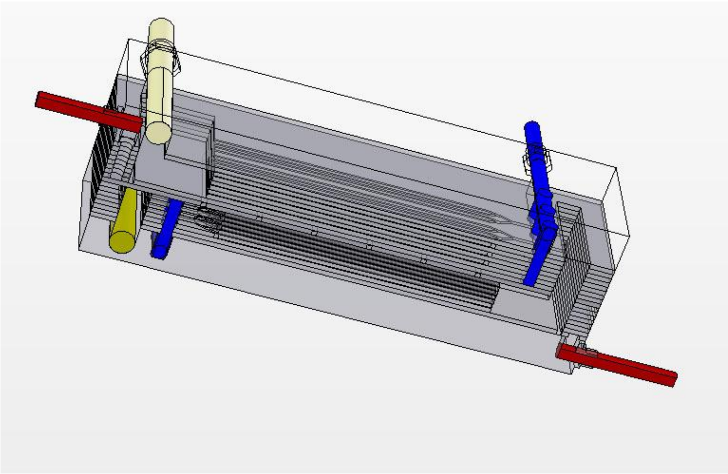


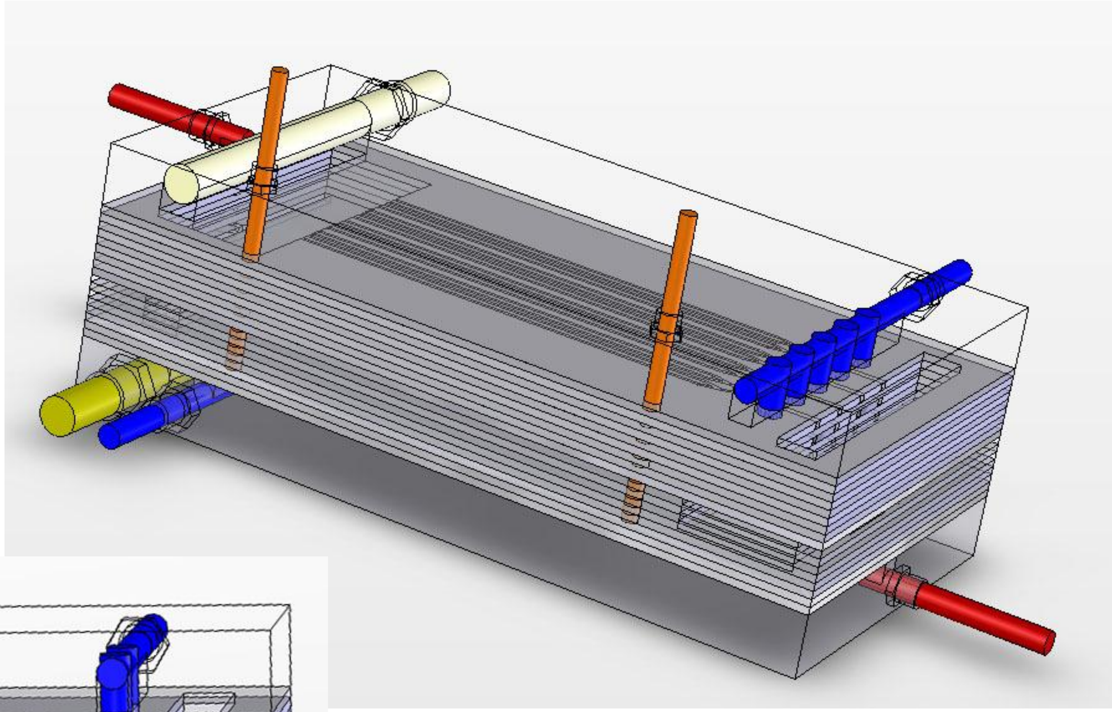


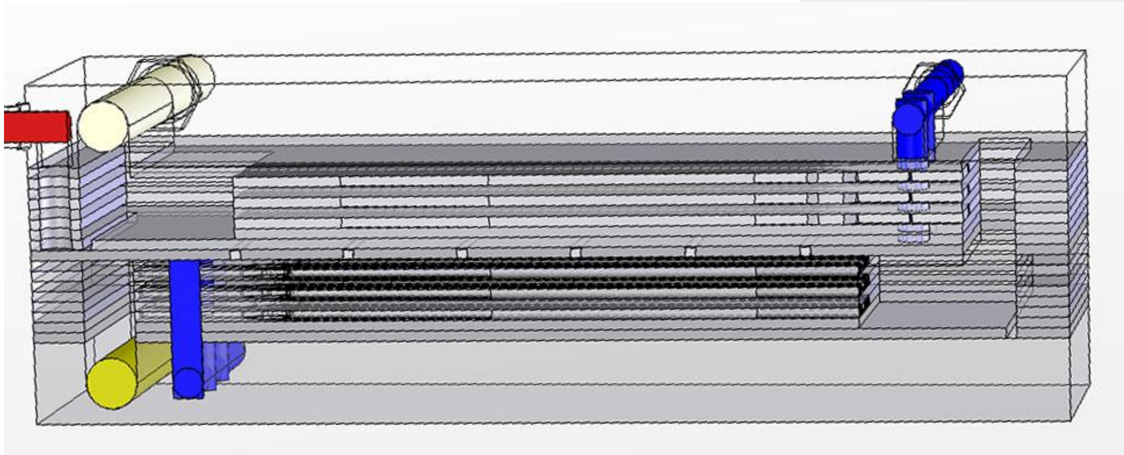
Biodiesel Production



Various Views - Biodiesel Microreactor







Biodiesel

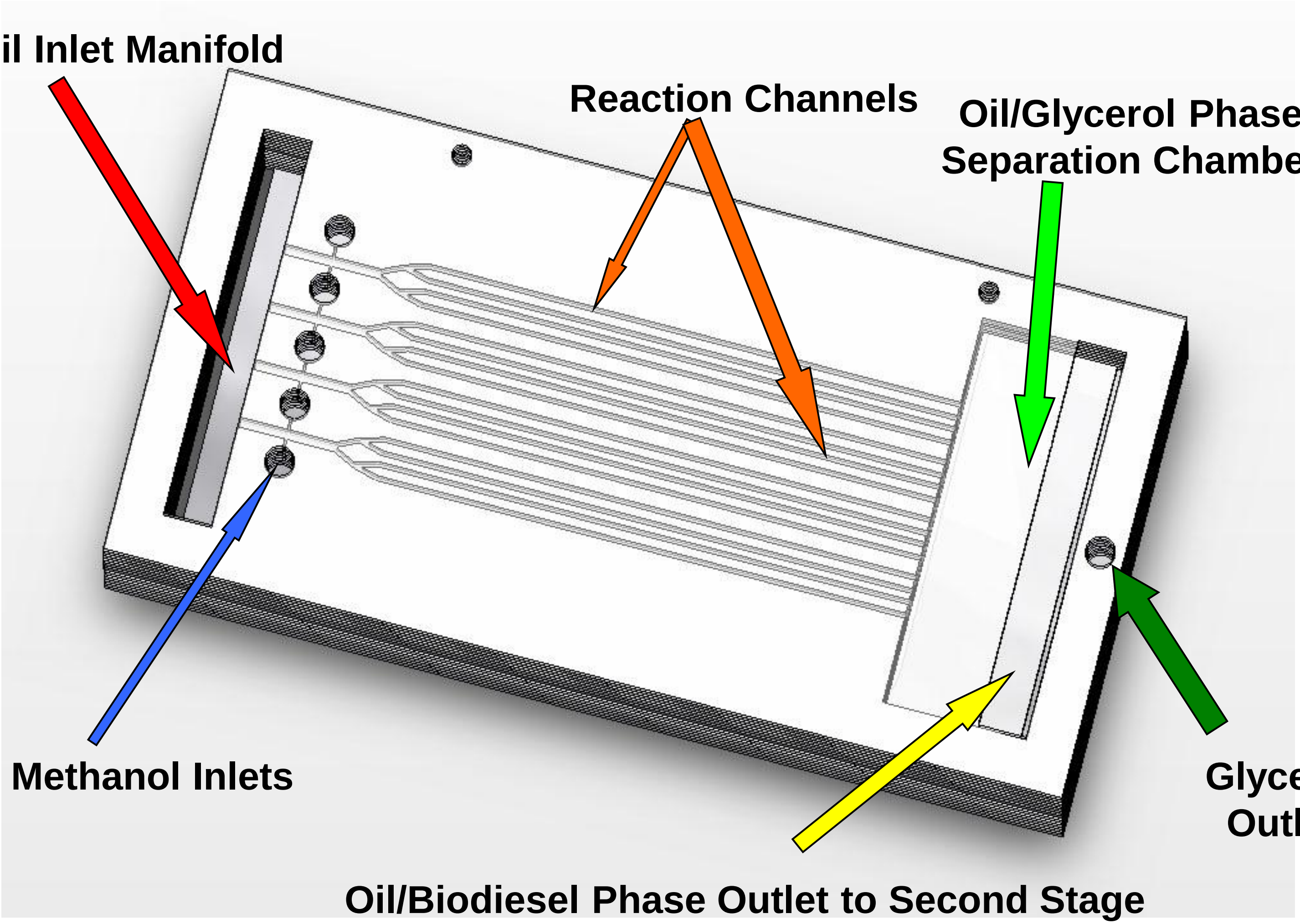
Heating Fluid

Methanol

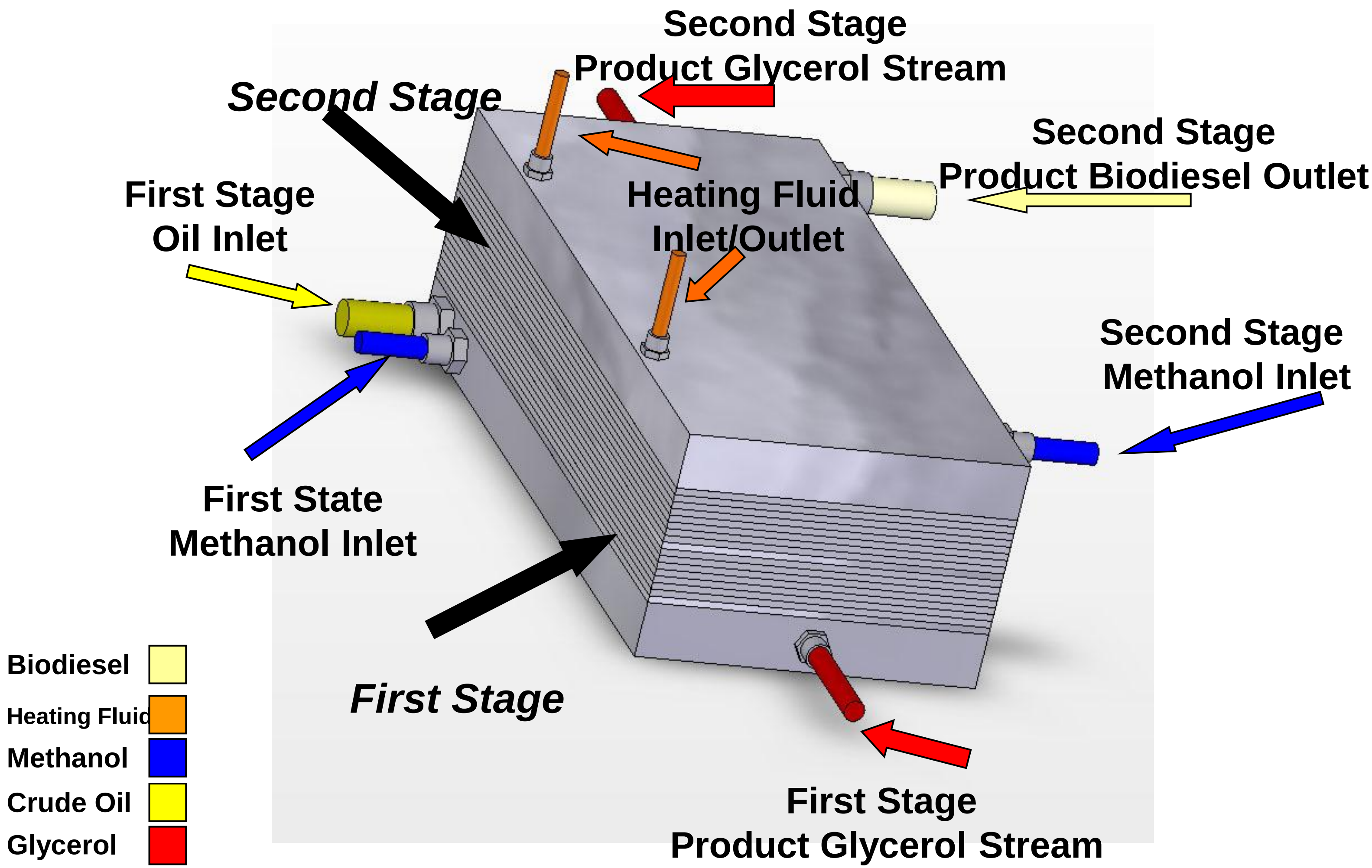
Crude Oil

Glycerol

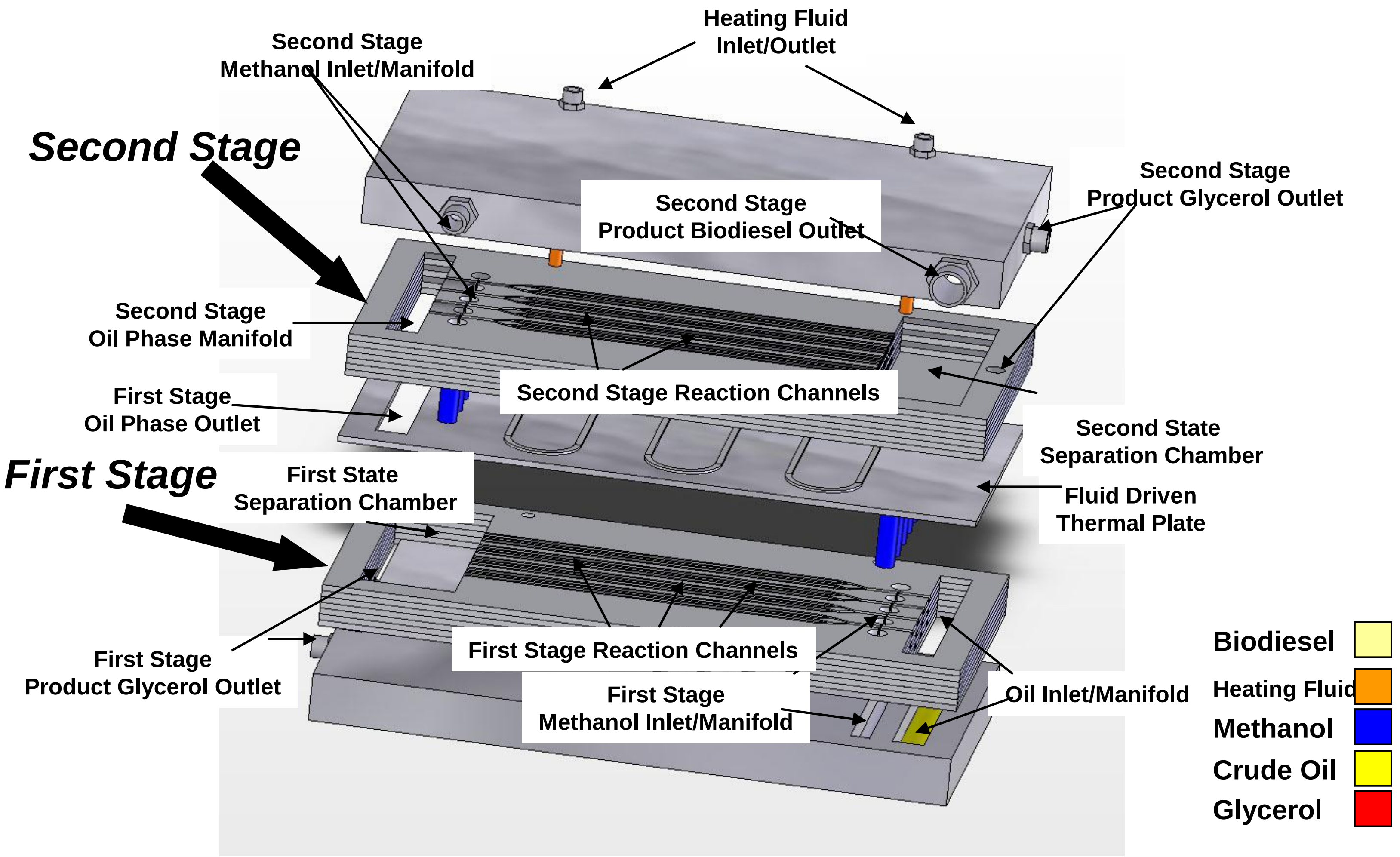
Single Stage Biodiesel Microreactor



Two Stage Biodiesel Microreactor



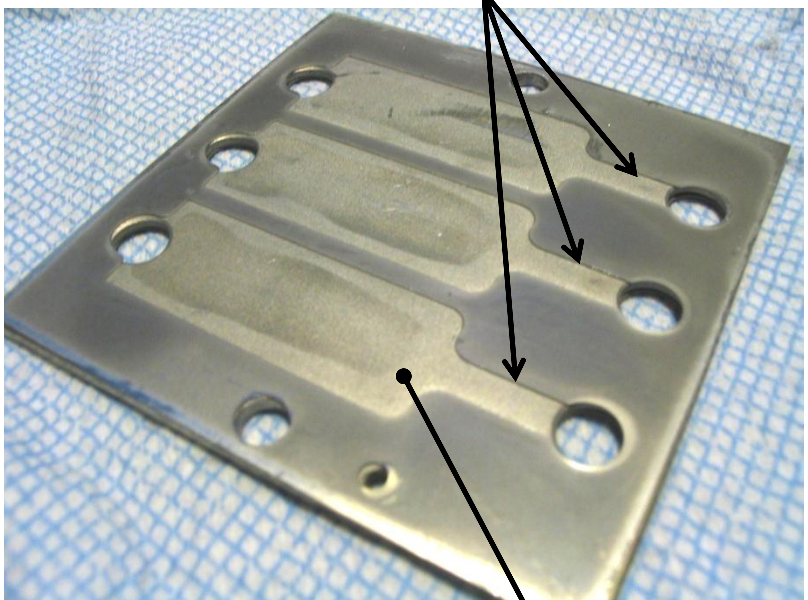
Exploded View - Biodiesel Microreactor

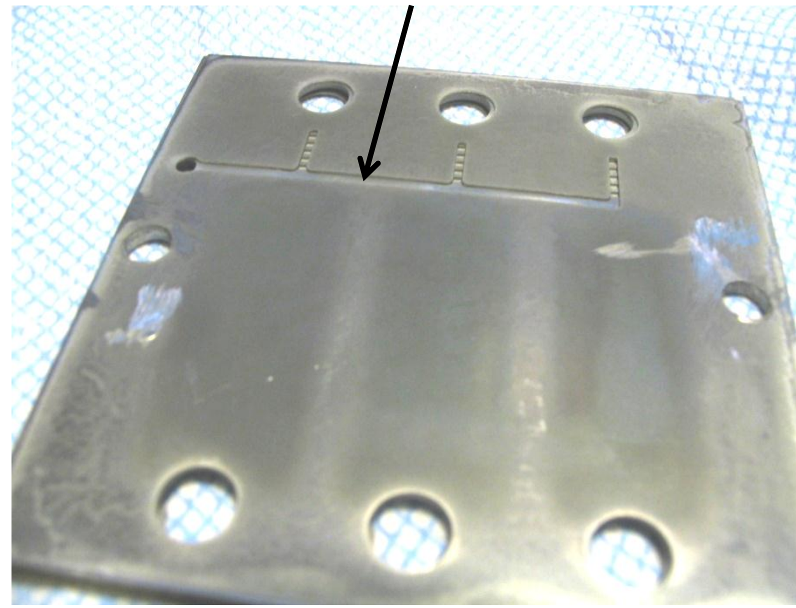


Micromixer Plates

Mixing Channels

Alcohol Feed Channel





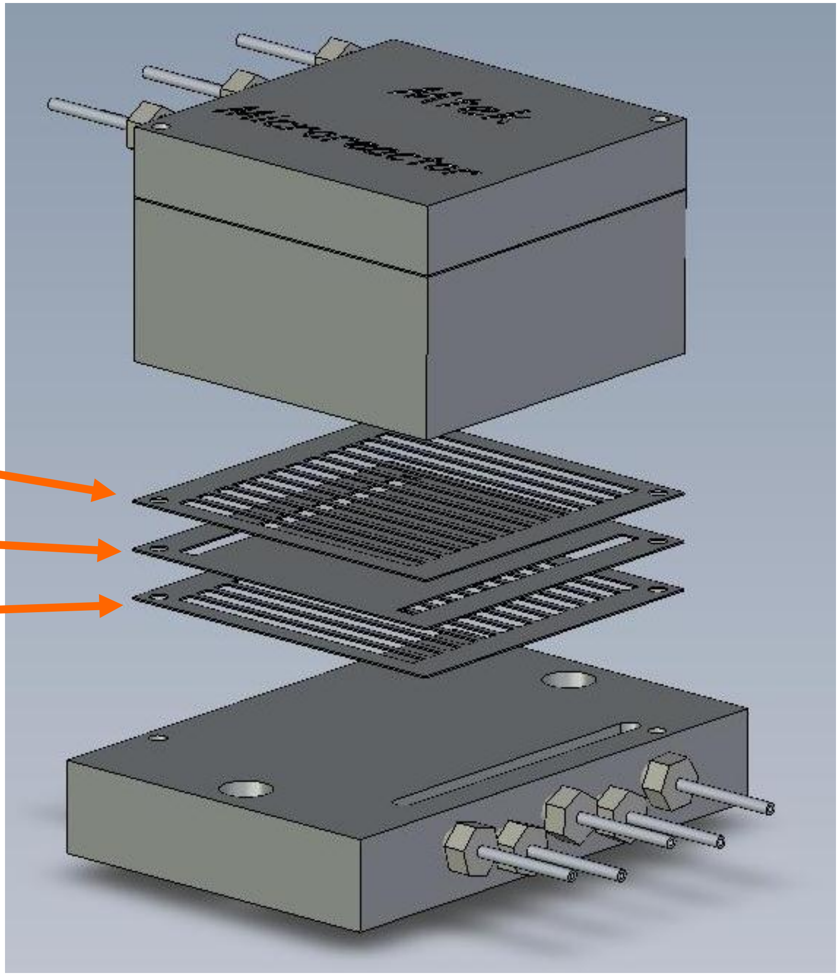
Sintered SS Plate

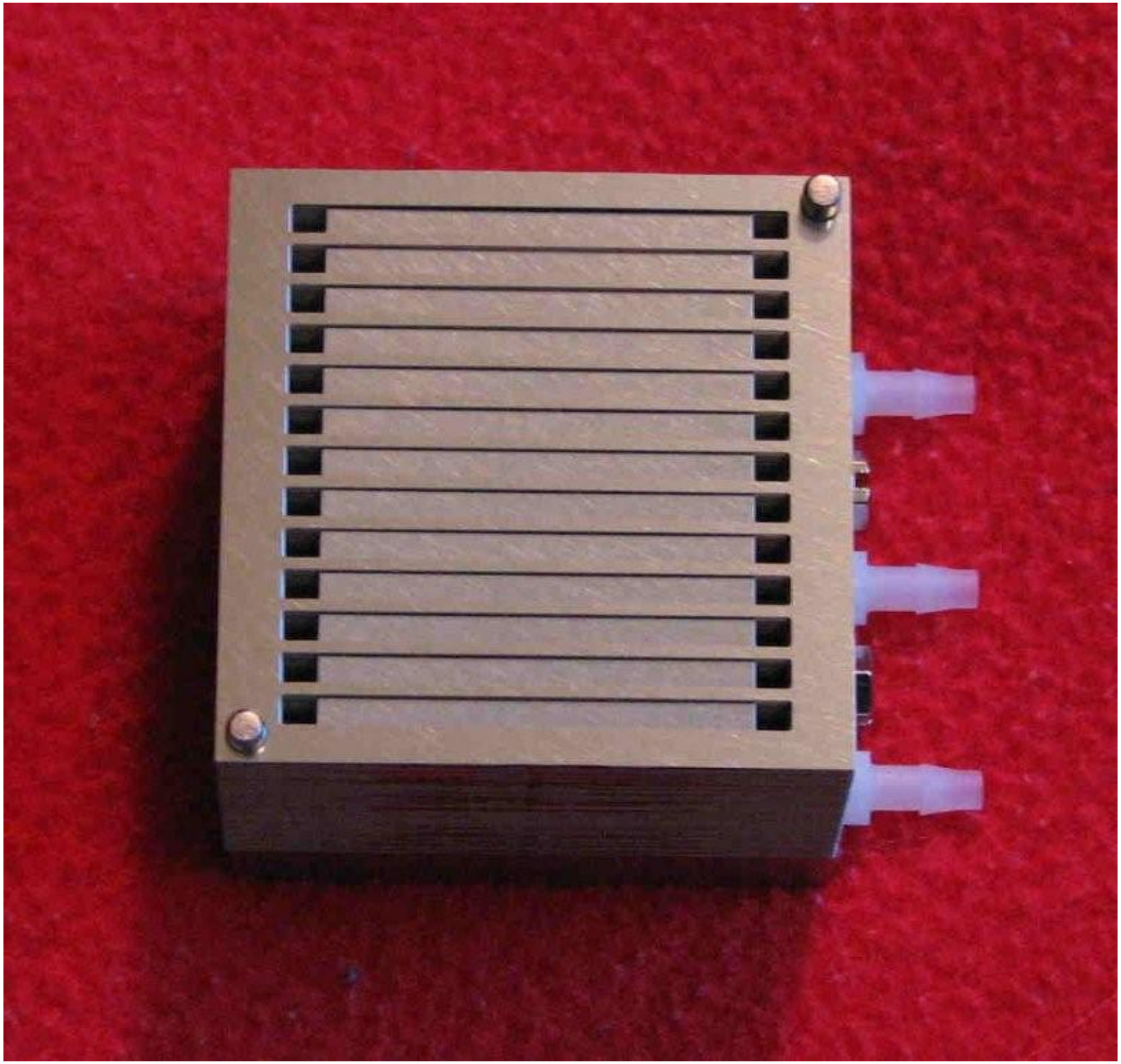
Microreactor Design

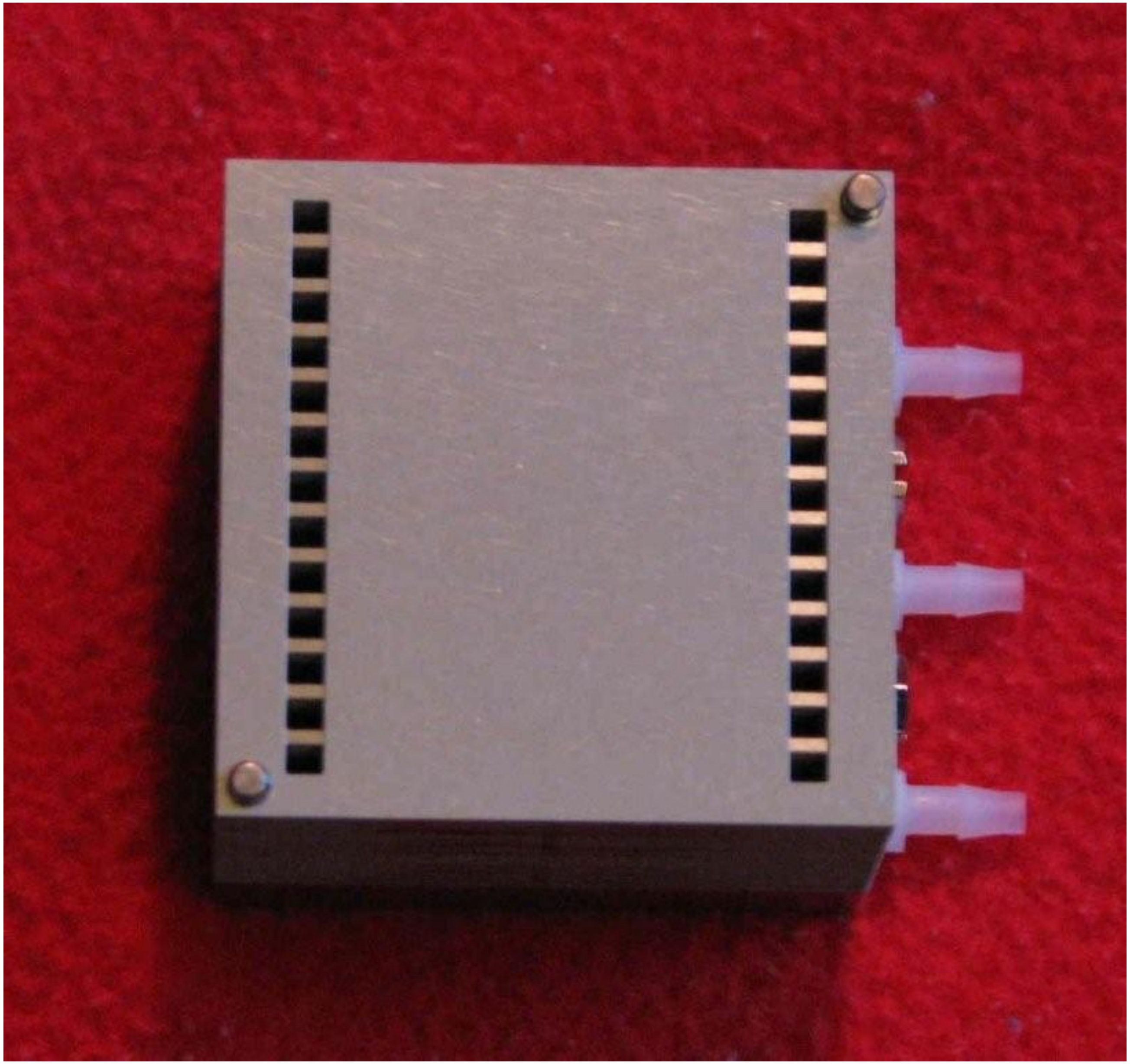
Reactor Channels

Separator Plate

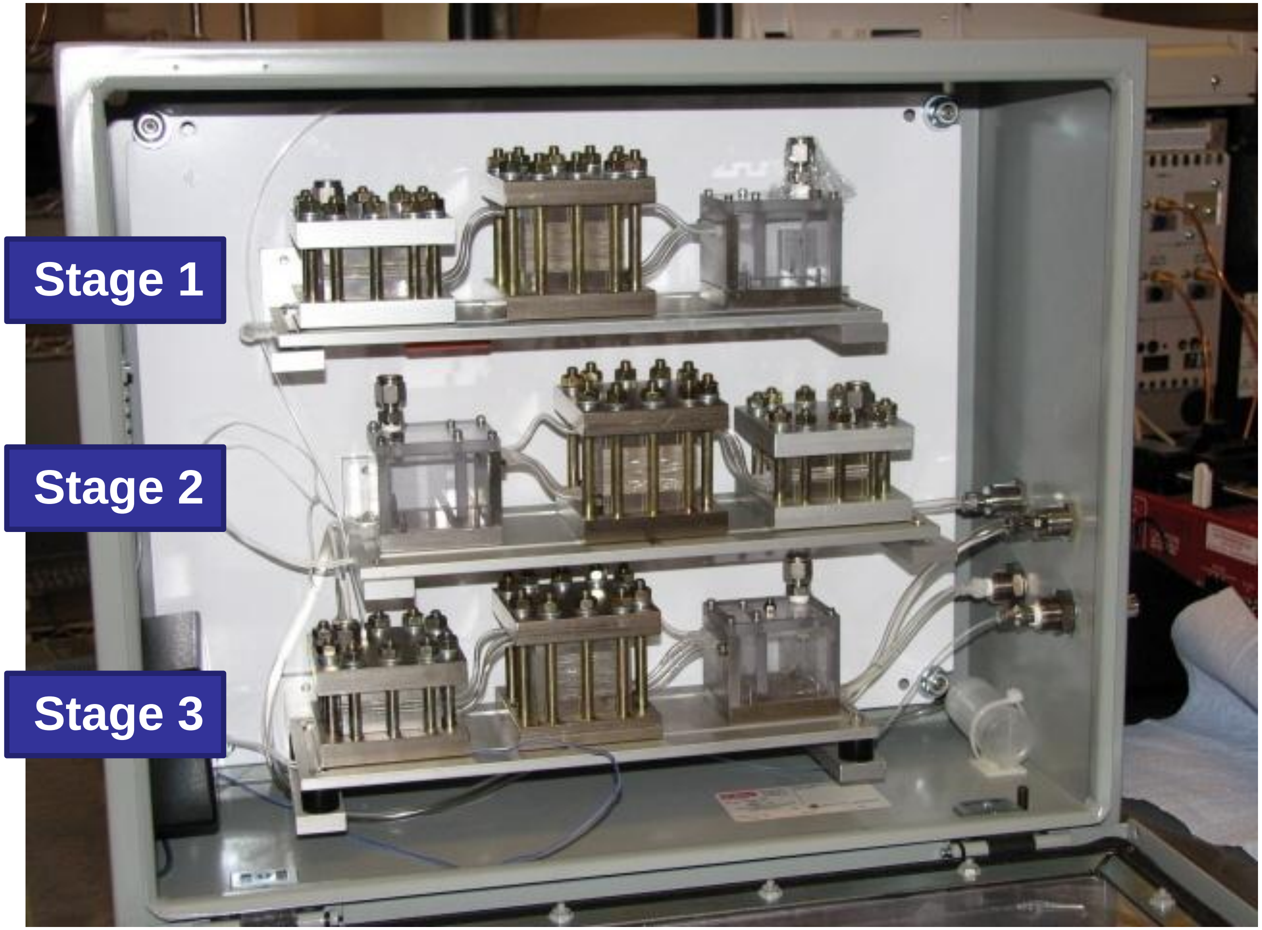
Reactor Channels







The Integrated 3-Stage Biodiesel Plant



<u>Size</u>

20” X 16” X 8”

<u>Capacity</u>

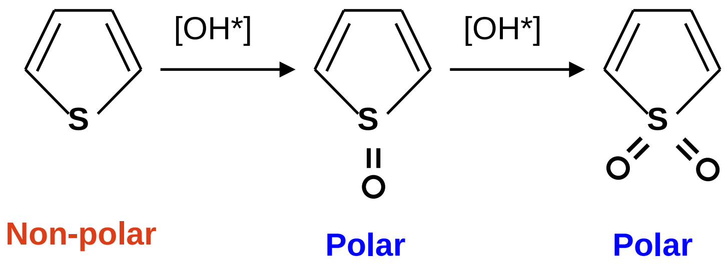
12ml/min =

~4.5 gal/day

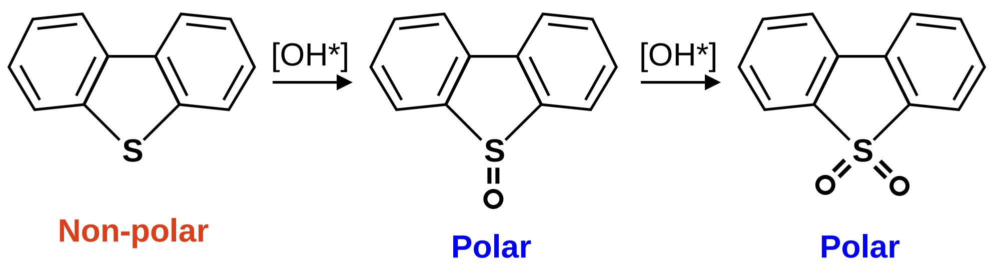
1500 gal/year

Oxidative desulfurization of fuels

Thiophene



Dibenzothiophene



Oxidative desulfurization - Reaction kinetics

The desulfurization reaction kinetics is approximated with a pseudo 1st order rate model. The pseudo 1st order approximation is associated with the overall degradation reaction of thiophene which consist of the following steps:

$$T \xrightarrow{h\nu,\ k_1} T^*$$

Activation of thiophene

$$H_2O_2 \xrightarrow{h\nu,\ k_2} H_2O_2^*$$

Activation of oxidant

$$T^* \xrightarrow{k_{-1}} T$$

Deactivation of thiophene

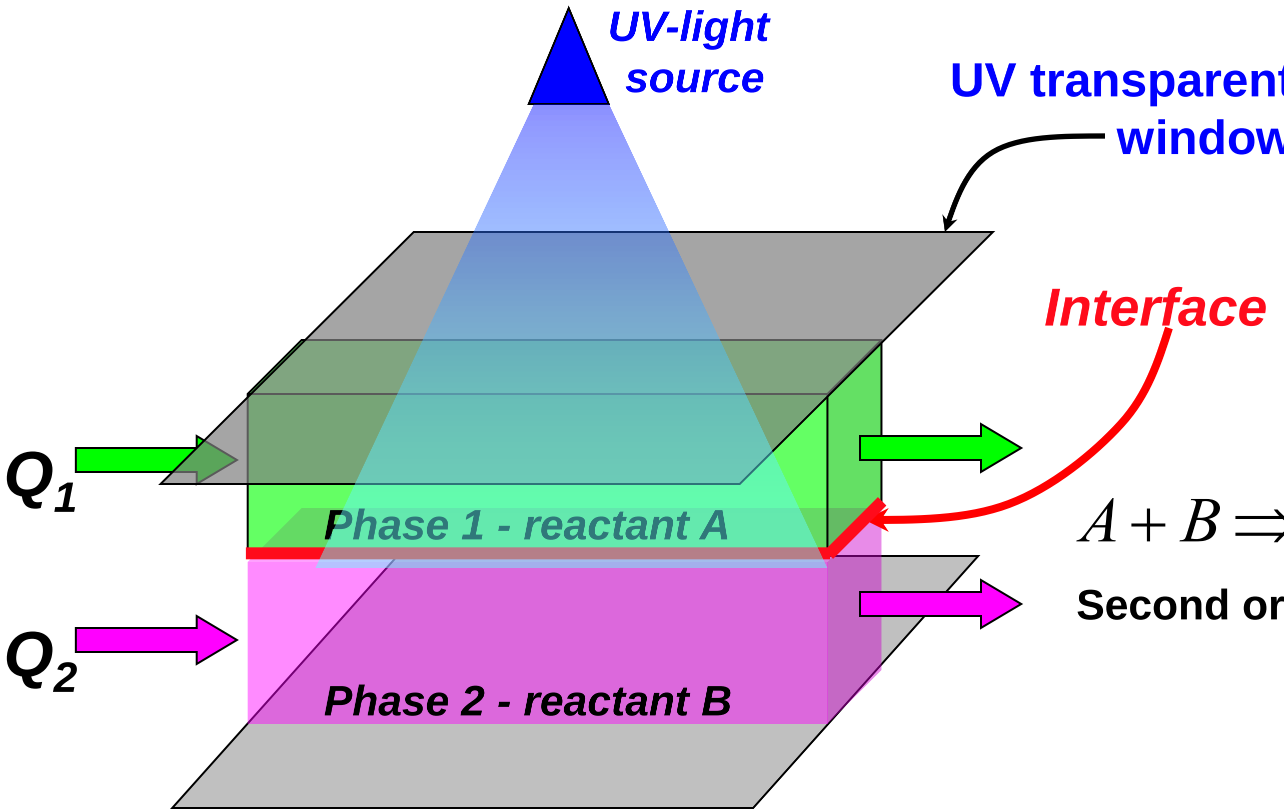
$$T^* \xrightarrow{k_3} \text{product}$$

Activated thiophene conversion

$$T + H_2O_2^* \xrightarrow{k_4} \text{products}$$

Thiophene conversion with activated oxidant

Desulfurization of Fuels Two-phase microreacto

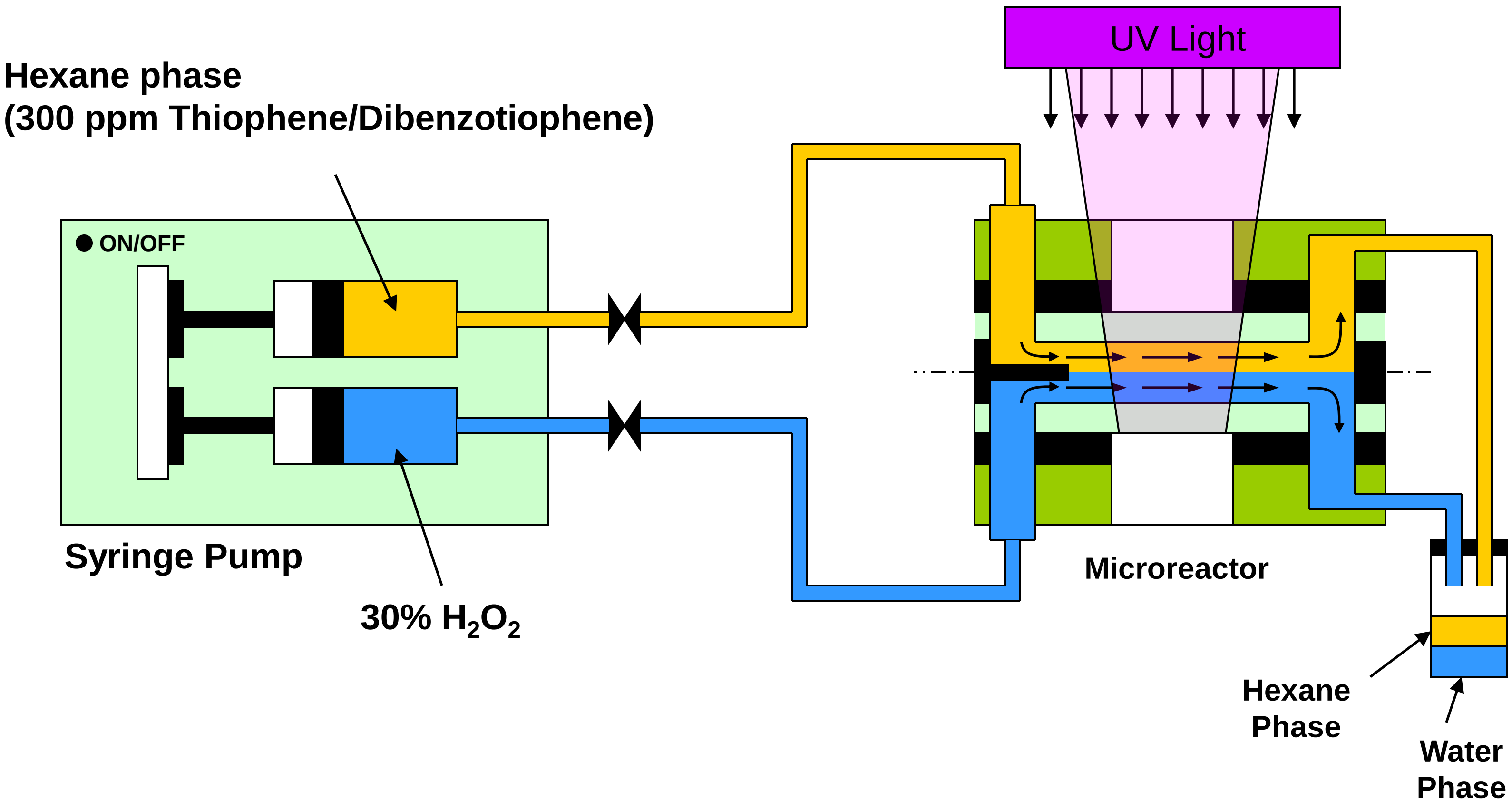


$$A + B \Rightarrow R \qquad -r_A = kC_AC_B$$

Second order chemical reaction;

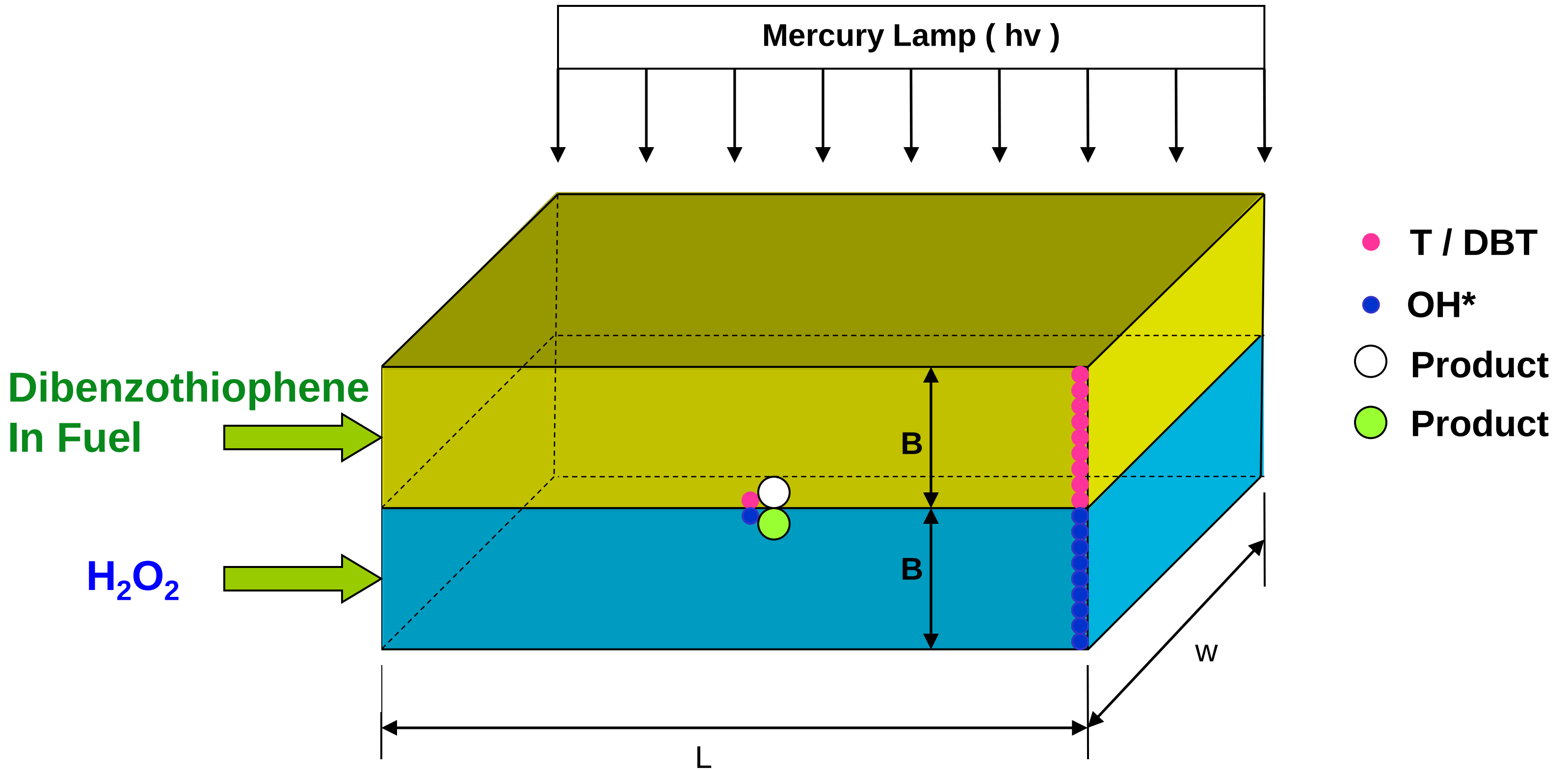
- **Two reactants enter micro-channel separately with flow rates Q_1 and Q_2;**
- **Two phases have different properties (D, ρ, μ, σ)**

Experimental Set-up

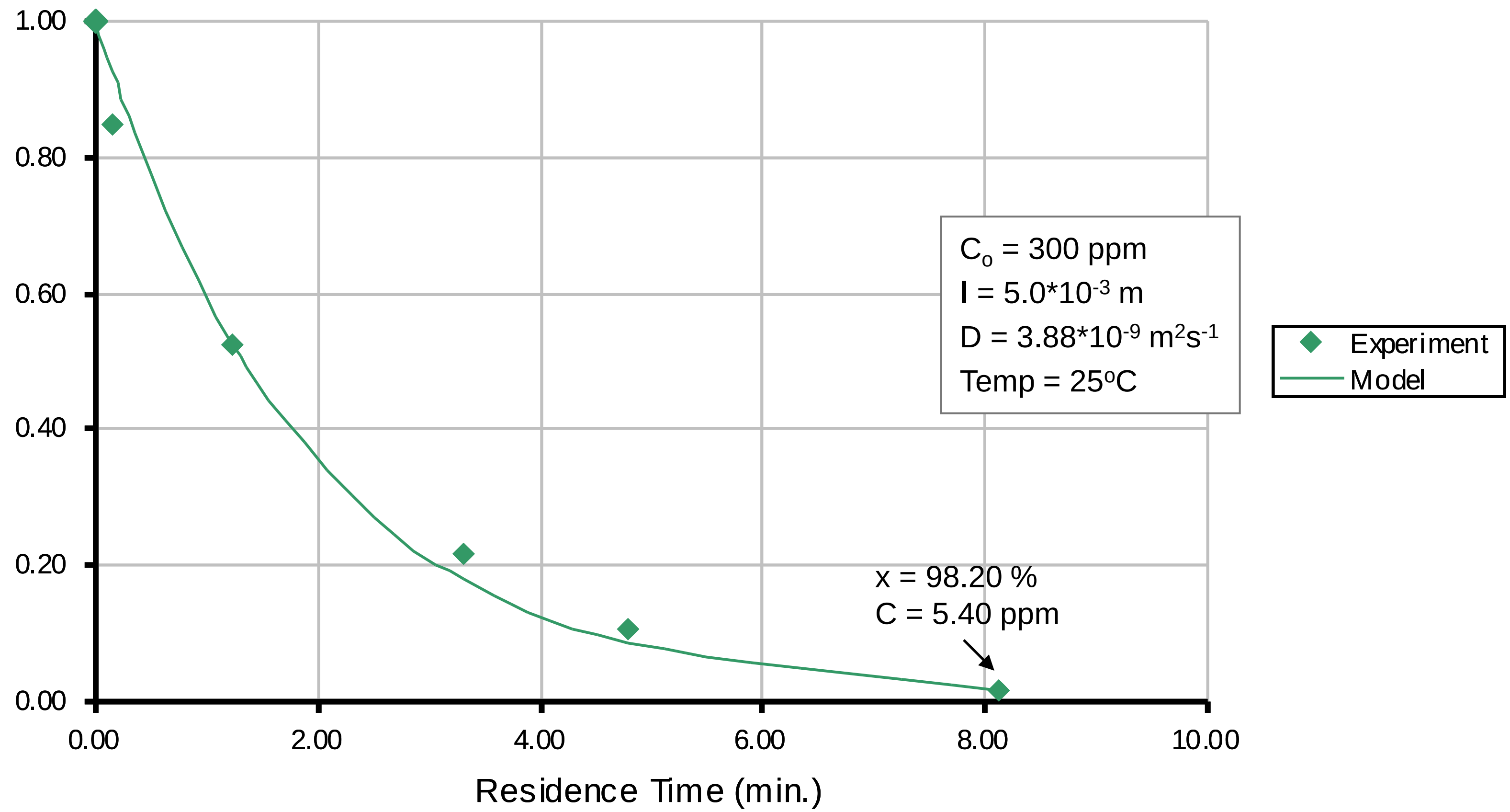


Experimental Setup for Interface Reactions

Desulphurization of Fuels

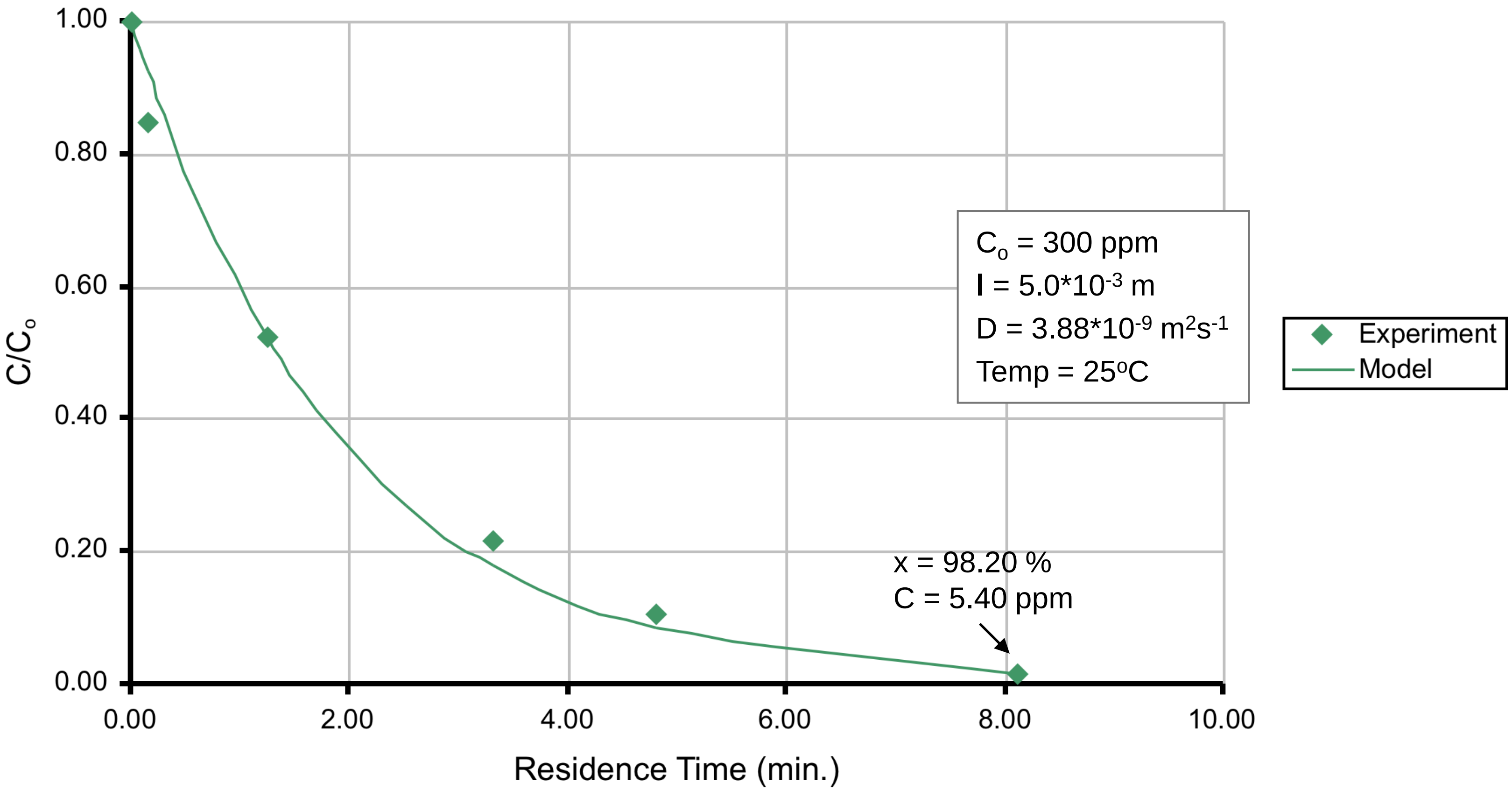


Experimental results
Desulphurization of Fuels

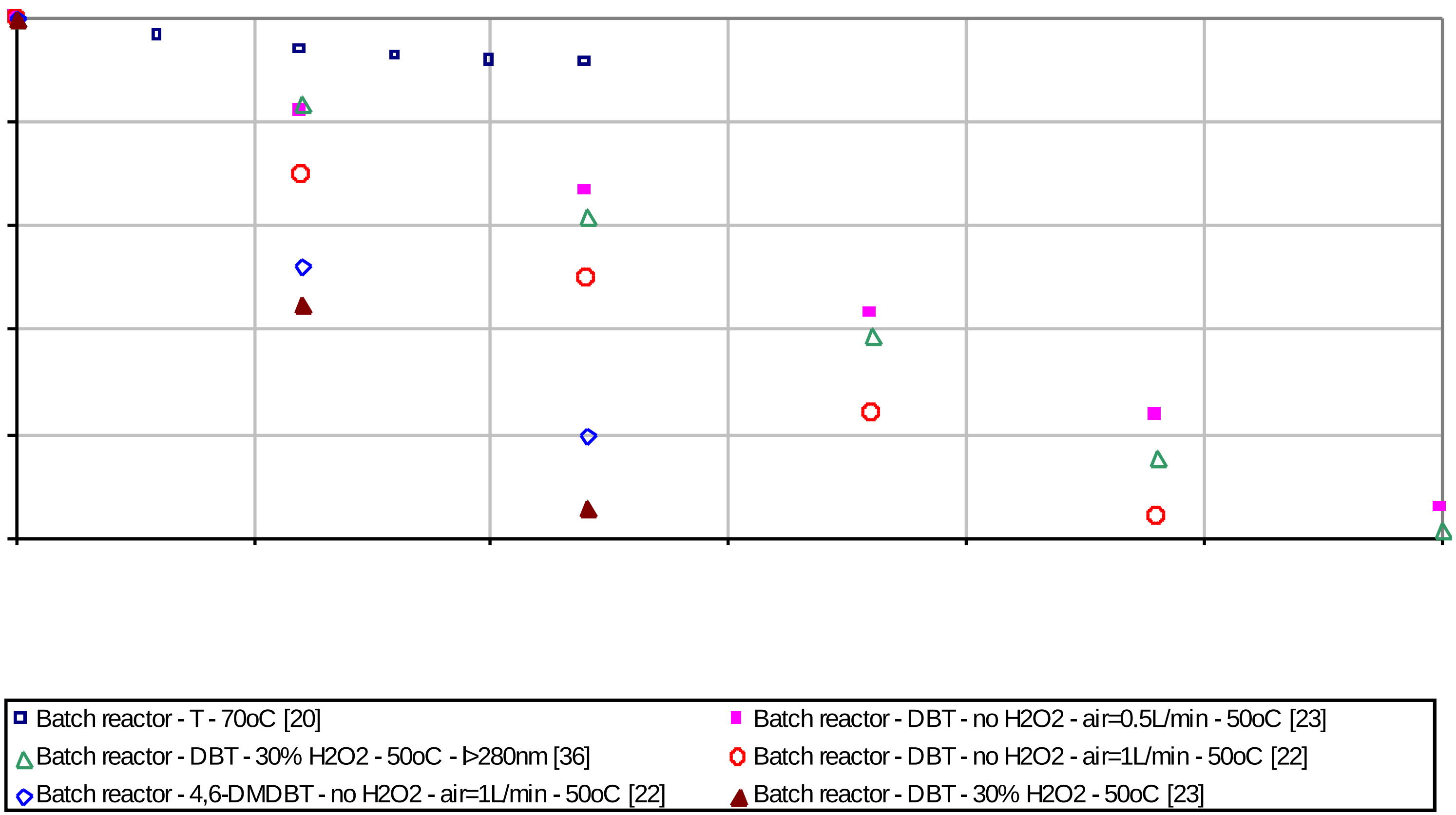


Experimental Results and Model Simulation

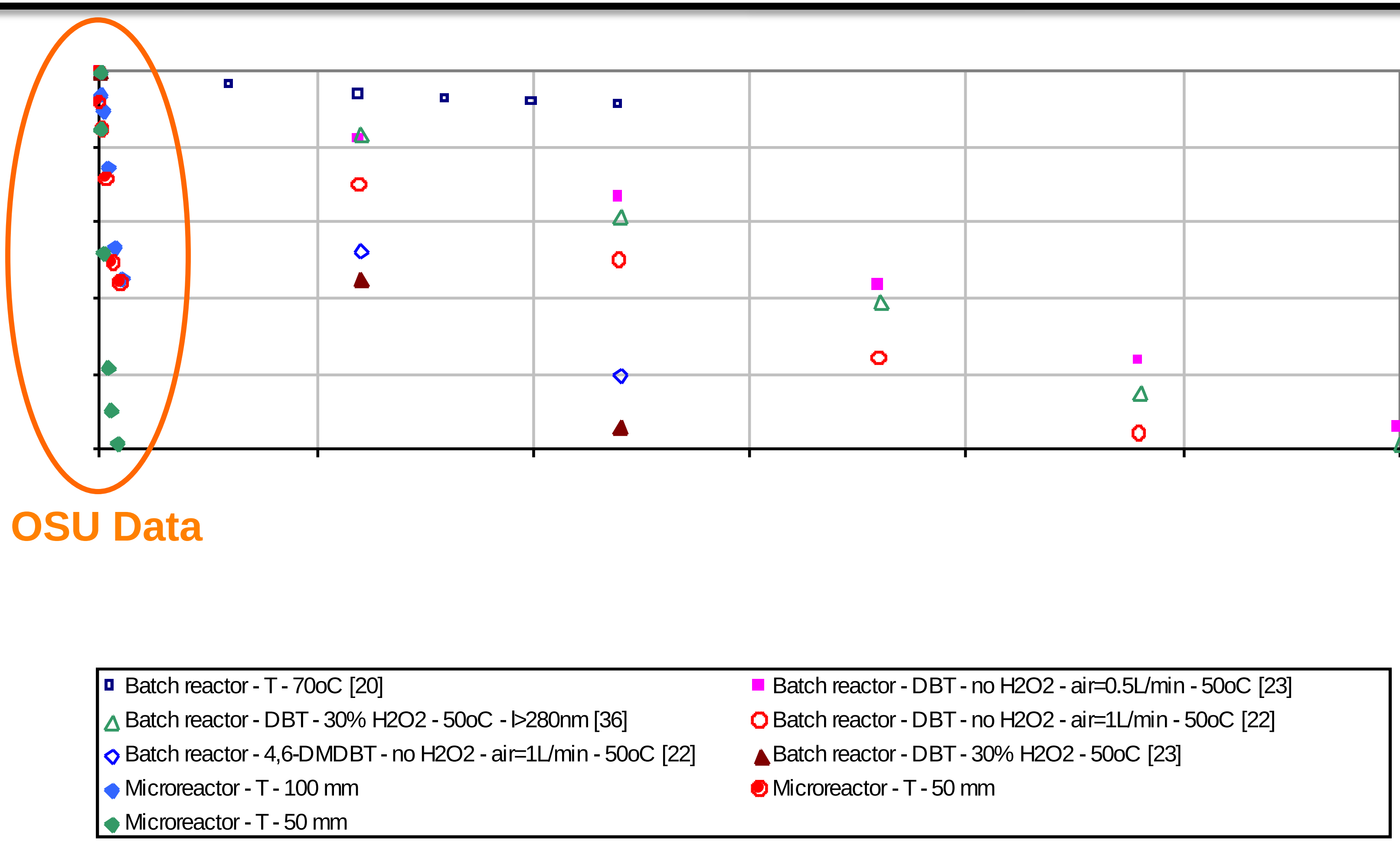
Thiophene concentration at spacer thickness = 50 µm



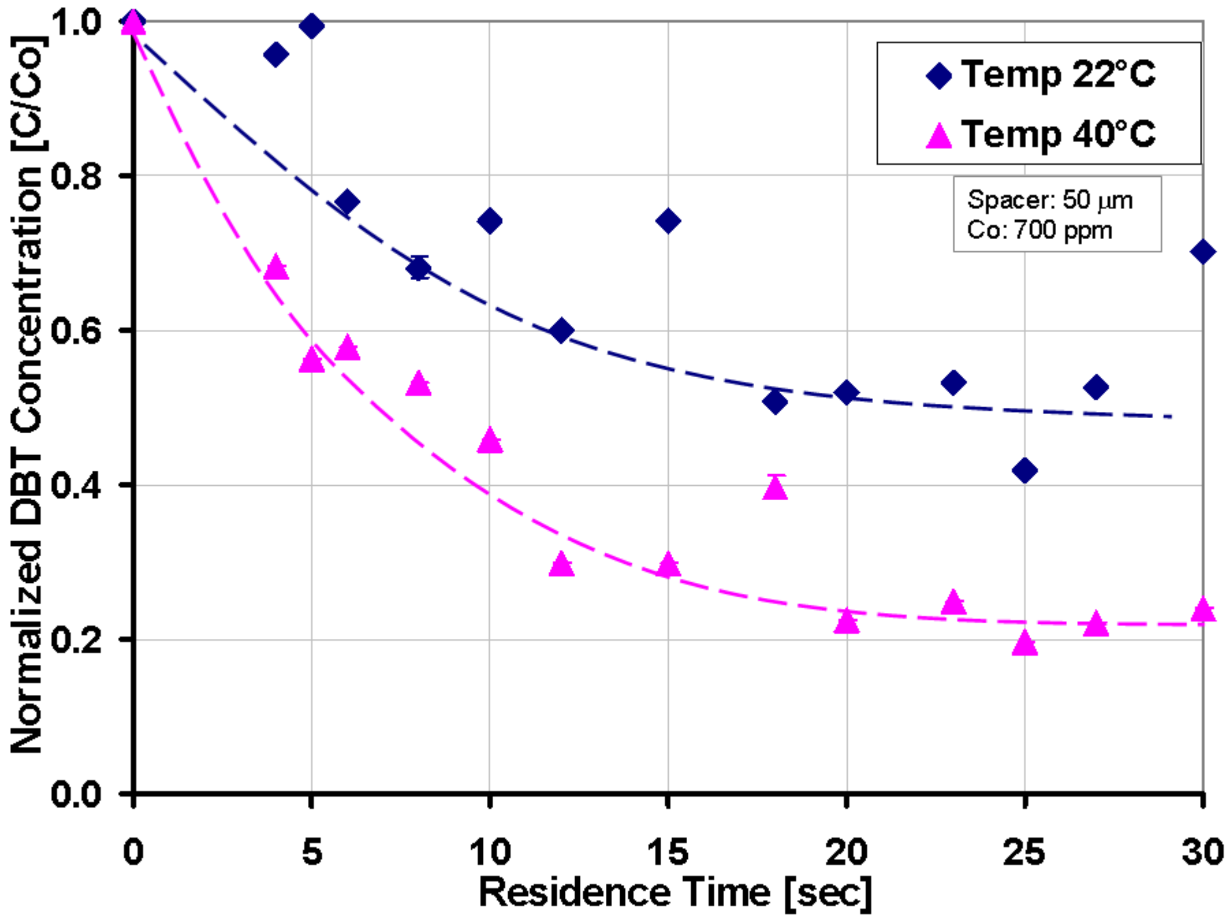
Published data by other researchers



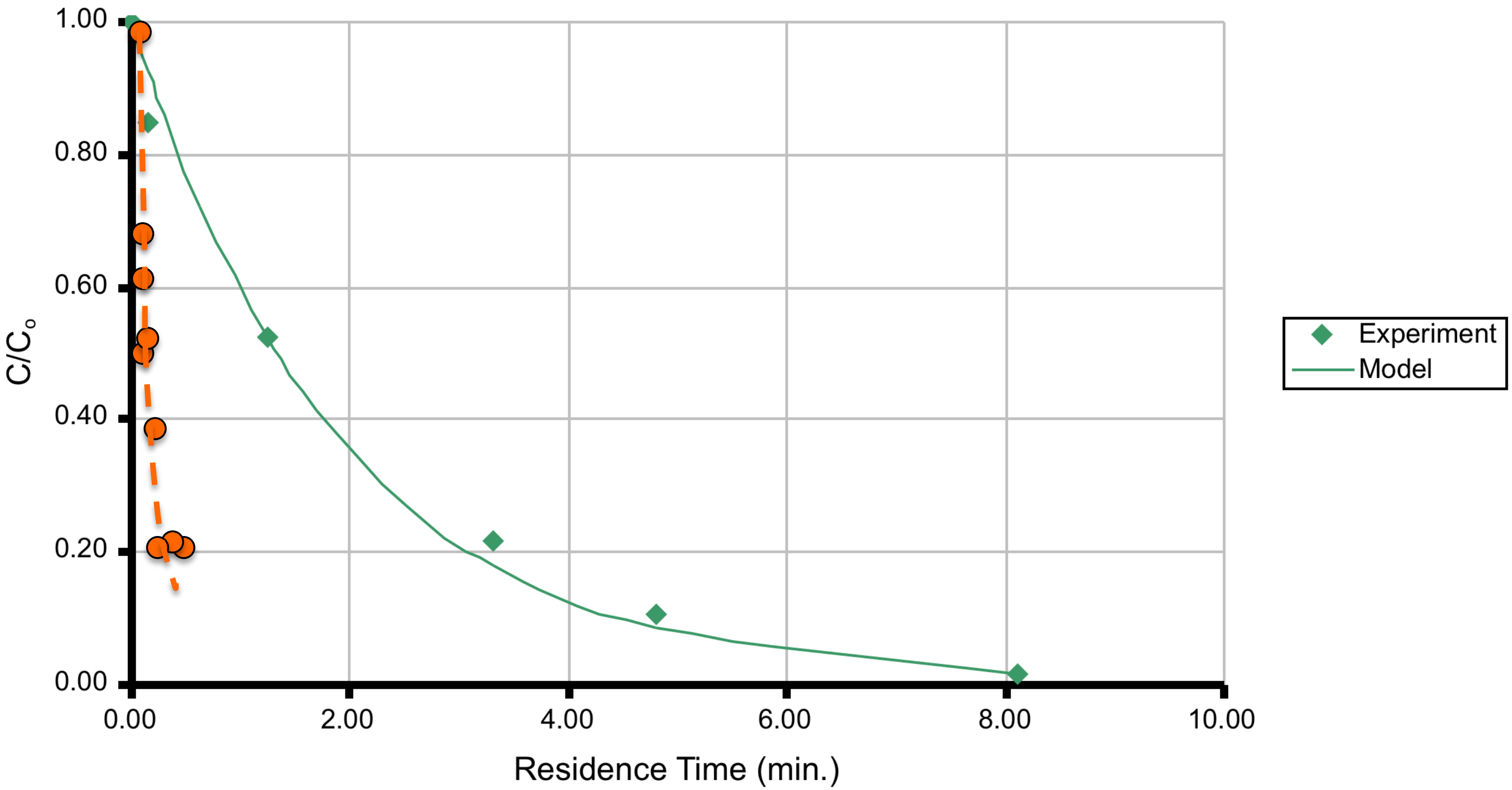
Comparison with other researchers



DBT Conversion at 50 μm Homogenous Microreactor



DBT Conversion in 50 μm Microreactor

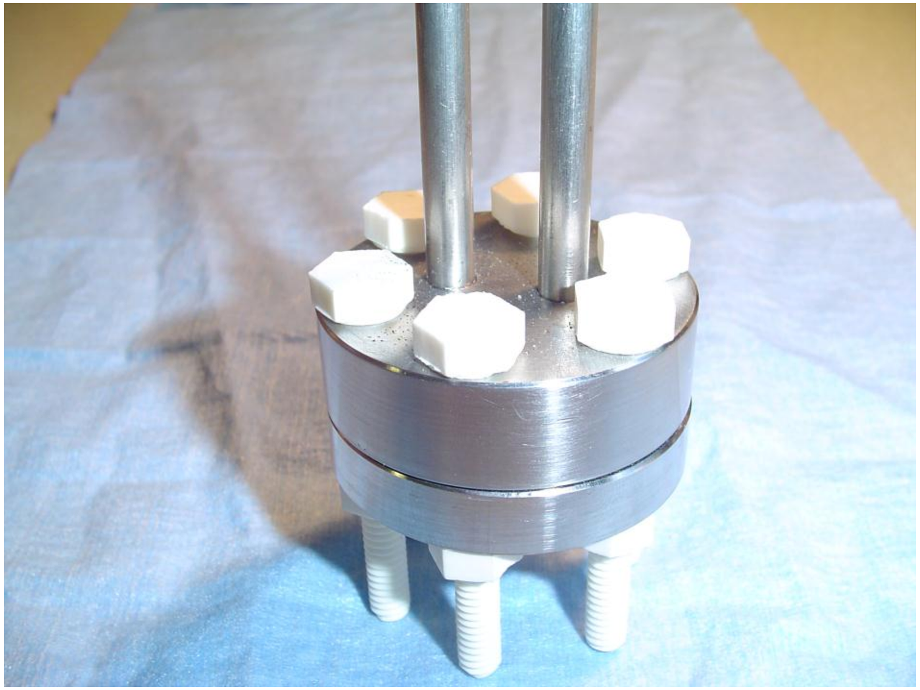


Microtechnology Based Processes

Steam Reforming of CH_4 and Biodiesel

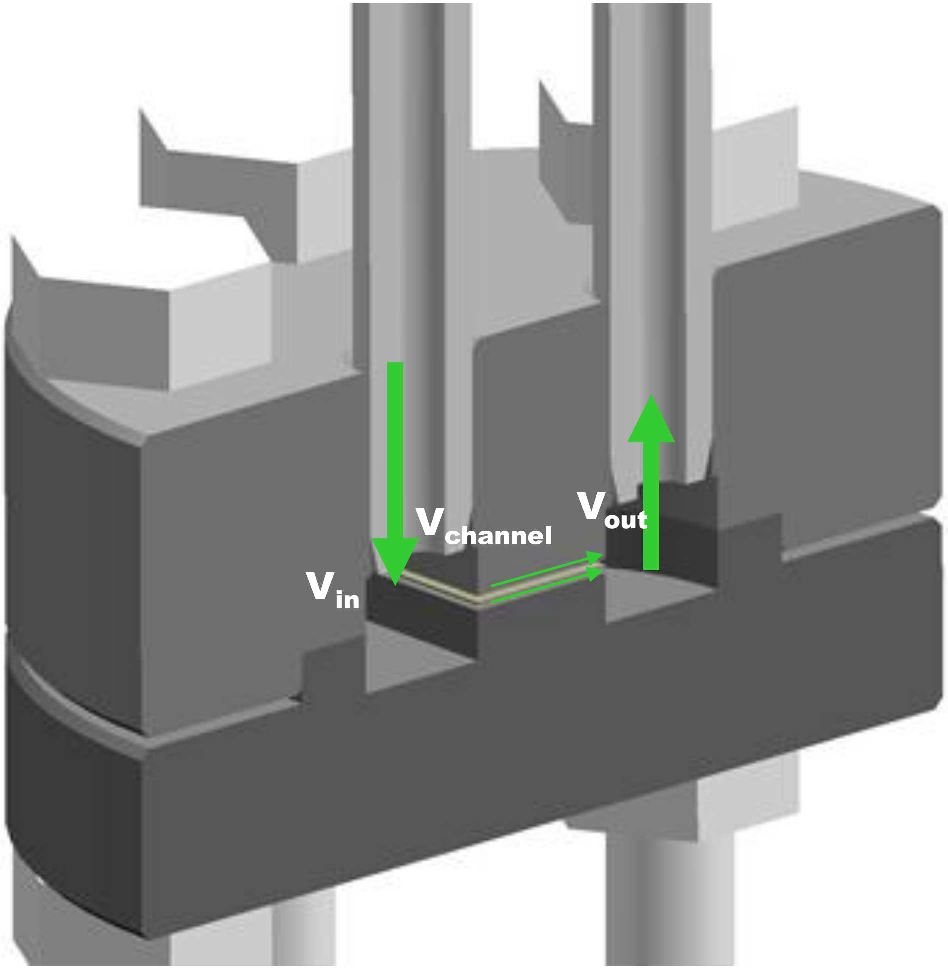
Two 25.0 mm × 7.5mm × 220 µm microchannels separated by 200 µm catalyst support plate with a catalytic surface of 165 mm^2

T=1000^{o}C



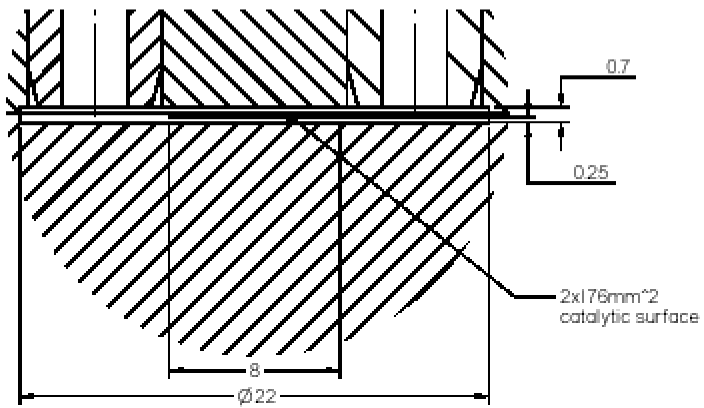
Microtechnology Based Processes

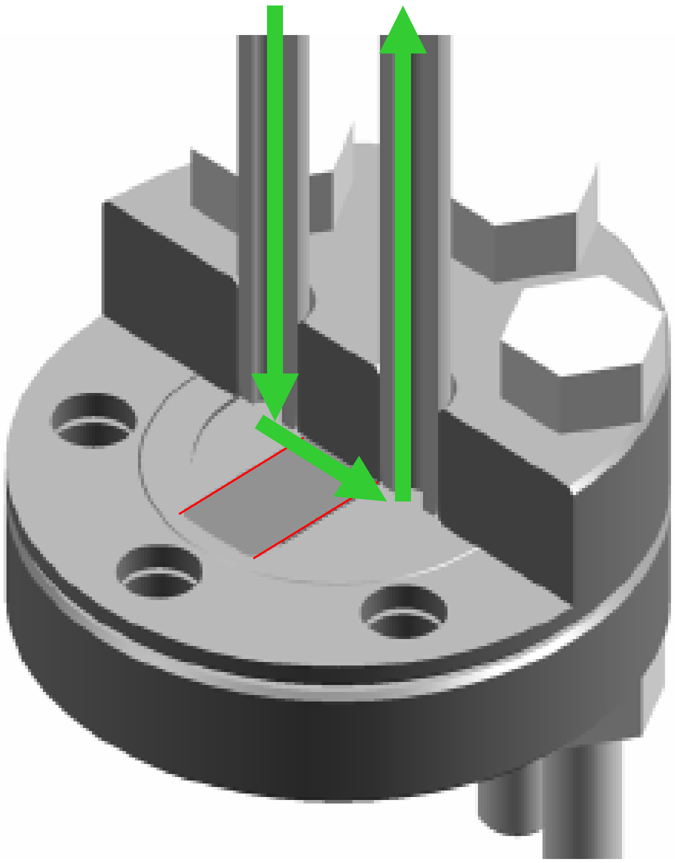
Steam Reforming of Hydrocarbons



Microtechnology Based Processes

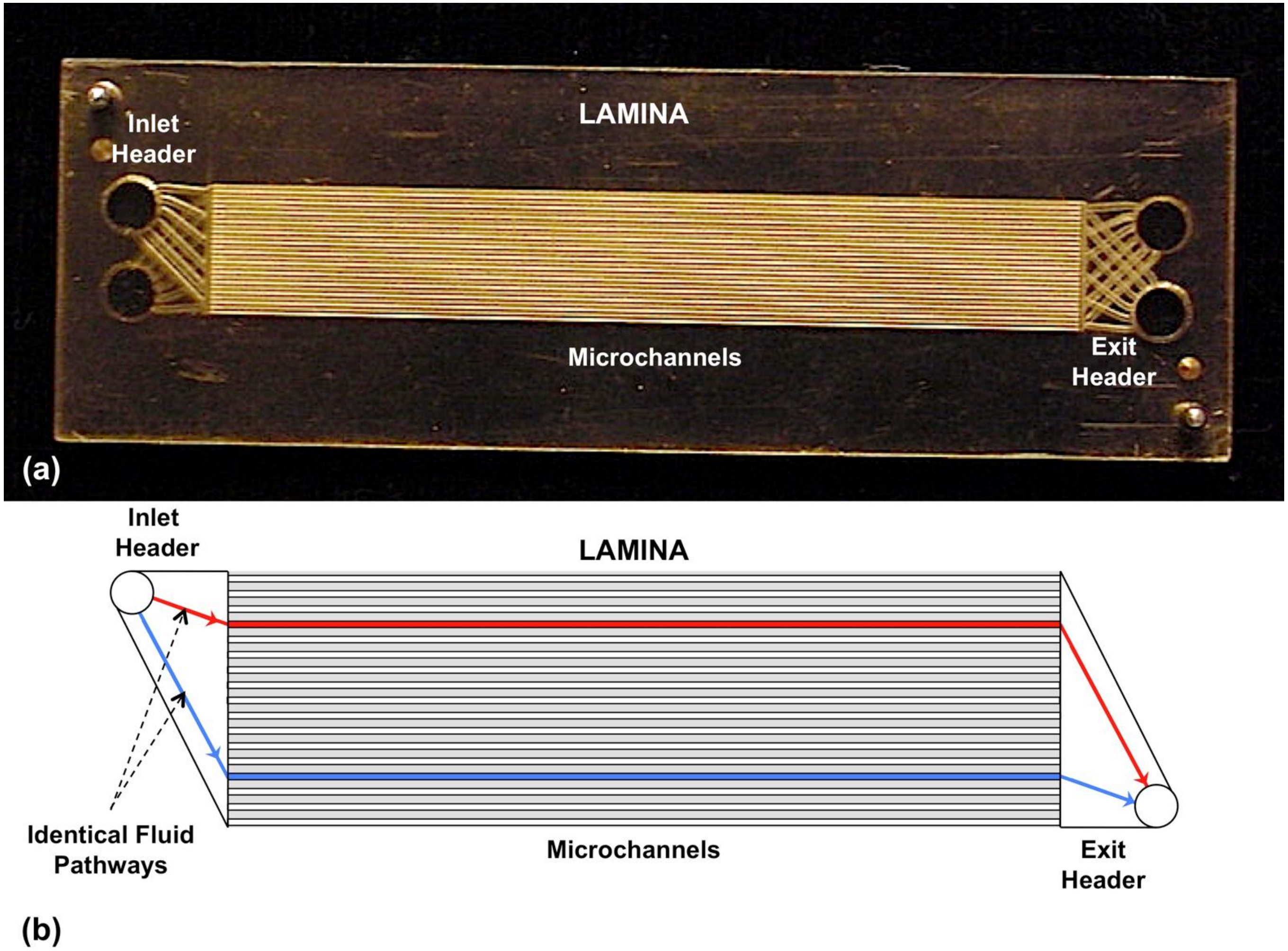
Steam Reforming of Hydrocarbons



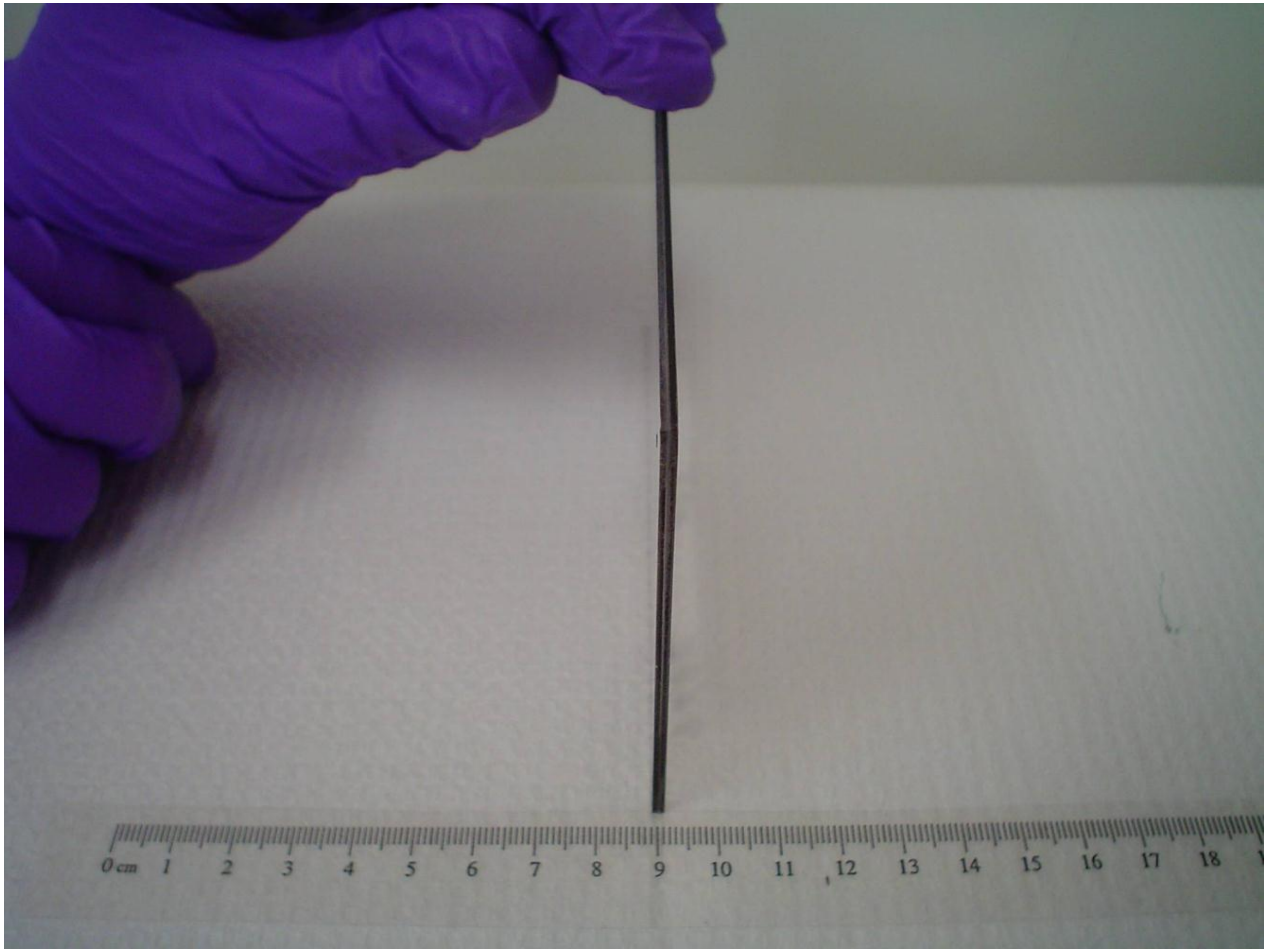


Curtsey of Dr. Al-Khaldi

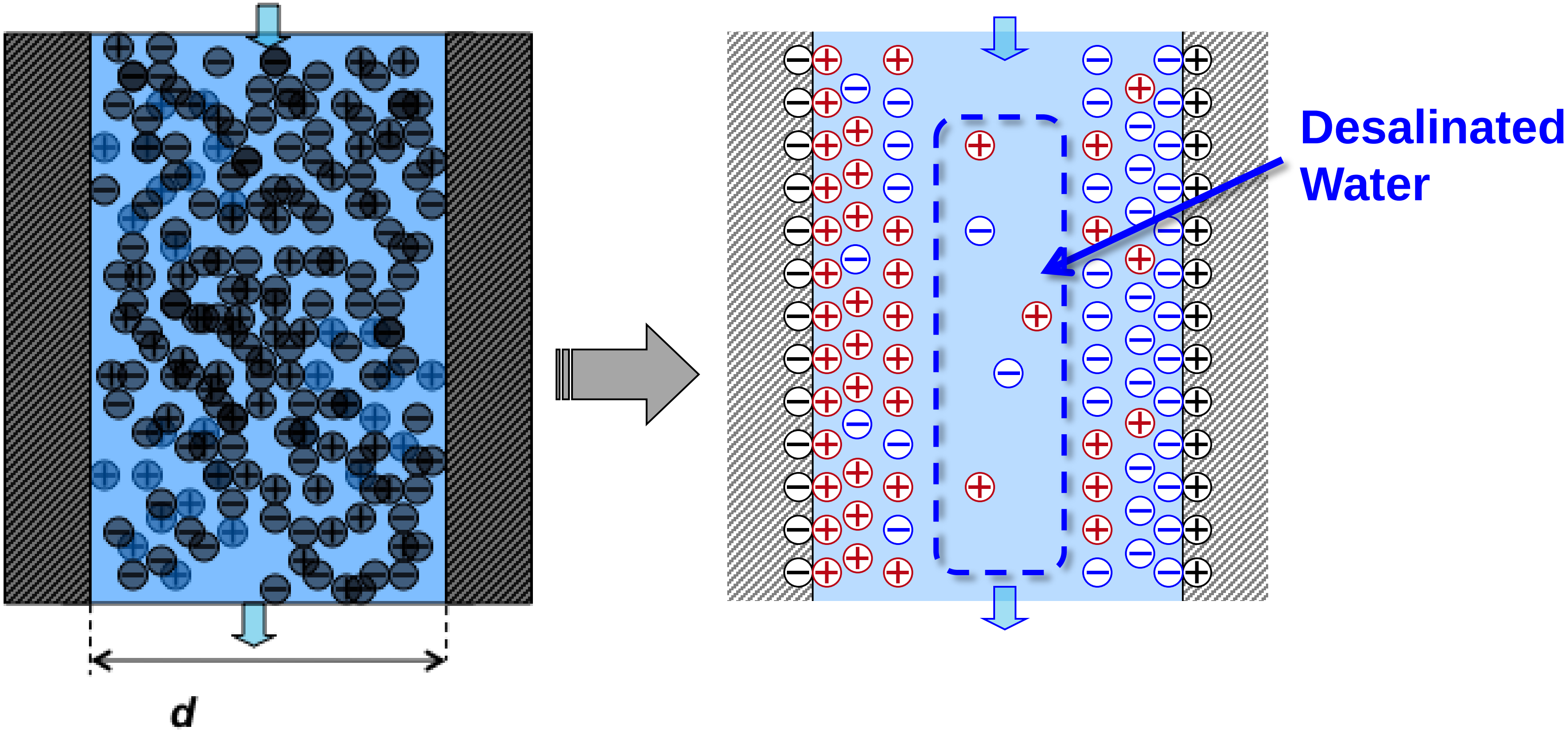
Microtechnology Based Hemodialyzer



Microtechnology Based Hemodialyzer



Microtechnology Based Desalination
Capacitive Deionization Cell (CDT)



We expect the following advantages of Capacitive Desalination over best commercially available technology (RO Desalination)

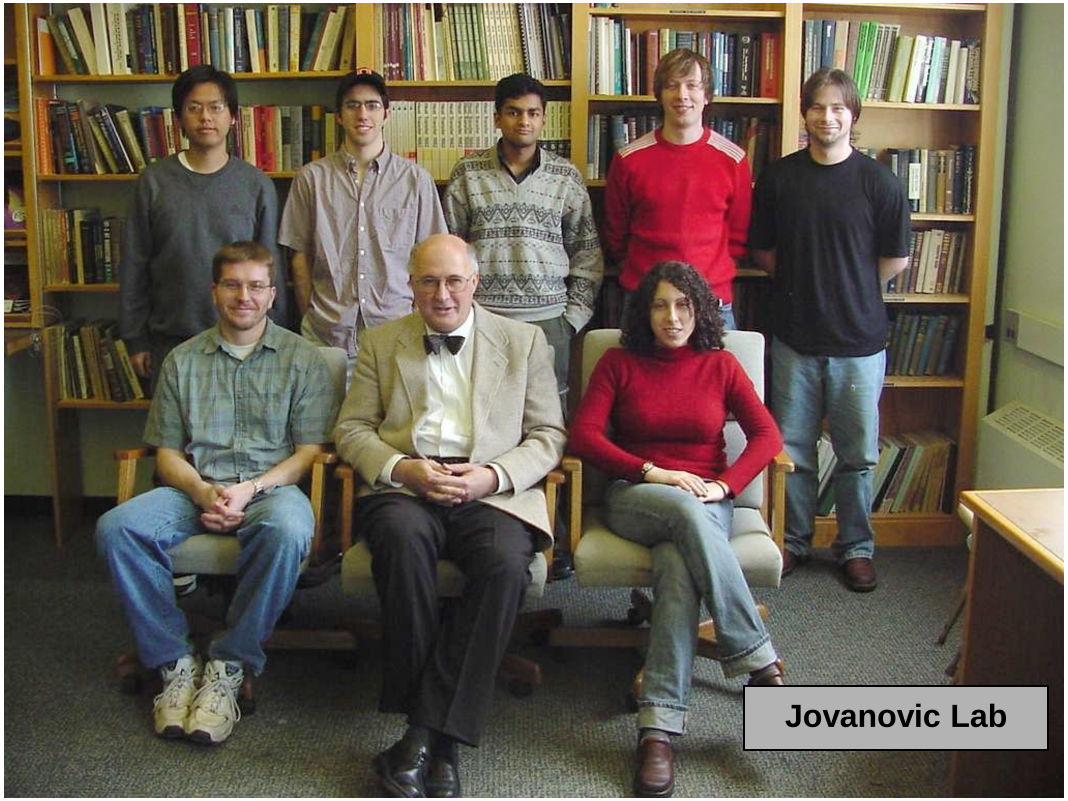
- The concept can approach the theoretical limit on minimum energy consumption; initially, we are projecting energy consumption of 1.5 – 4.0 [kWh/m^3] fresh water produced;
- Flexible capacity – from small to very large units (numbering-up v.s. scale-up)
- Possibility of use of renewable energy at the point of use (solar/wind)
- Lower capital investment;
- Lower operating cost;

Typical Development Steps

- Build and demonstrate a nominal size technology unit.
- Develop inexpensive large scale manufacturing technology for microscale devices.
- Educate new generation of PhDs capable of introducing Microtechnologies worldwide.
- Launch new small business ventures and create jobs.

Jovanovic's Microtechnology Team

Students are Our Greatest Asset



Ensuring a sustainable future requires well-educated students who are not afraid of new technological world.

- Kasidid Asumpingpong, M.Sc.
- James Parker, Ph.D
- Joy Das, M.Sc.
- Daniel Haller, Ph.D.
- Eric Anderson, Ph.D.
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Thank you for your attention!