MICROWAVE CATALYTIC SYNTHESIS OF AMMONIA

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DOE Ammonia for H_2@Scale Workshop

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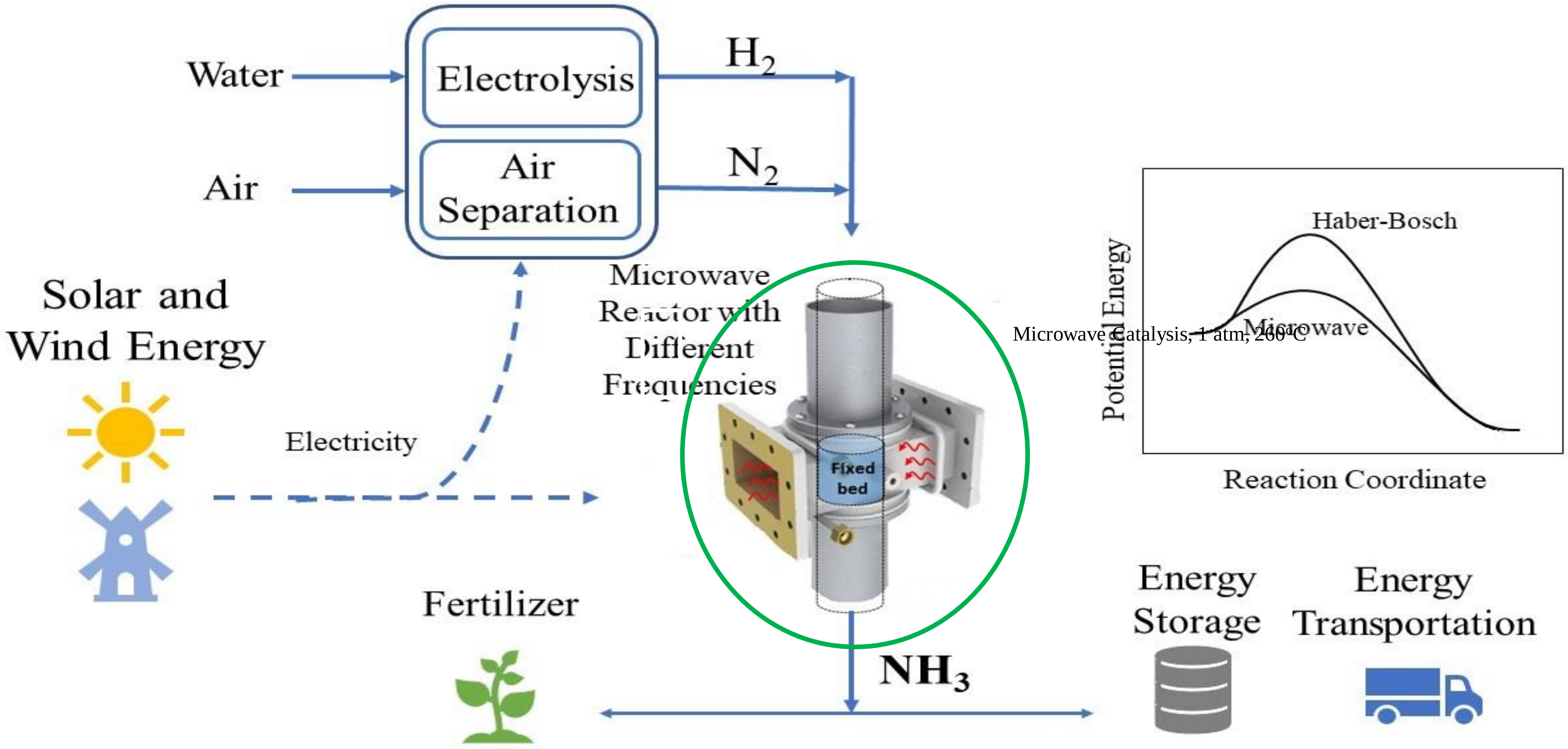
West Virginia University
National Energy Technology Laboratory (NETL)
Malachite Technologies
Shell

Renewable Power to Carbon-Neutral Liquid Fuel



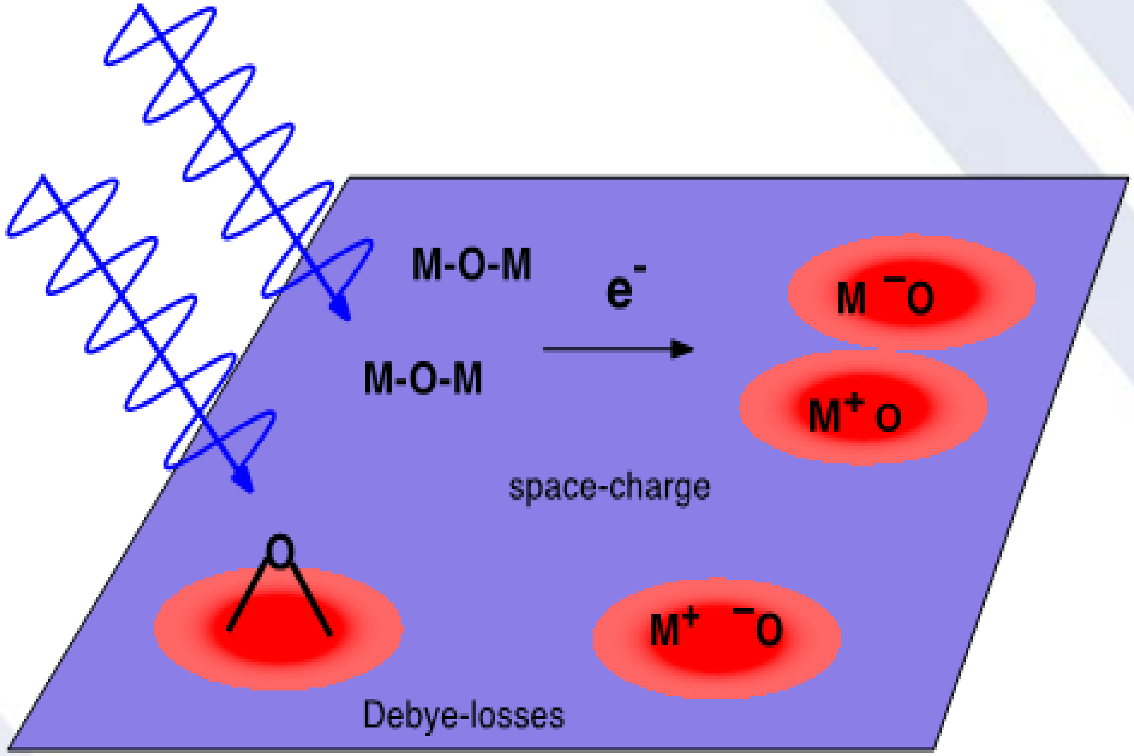
Microwave Catalysis, 1 atm, 260°C

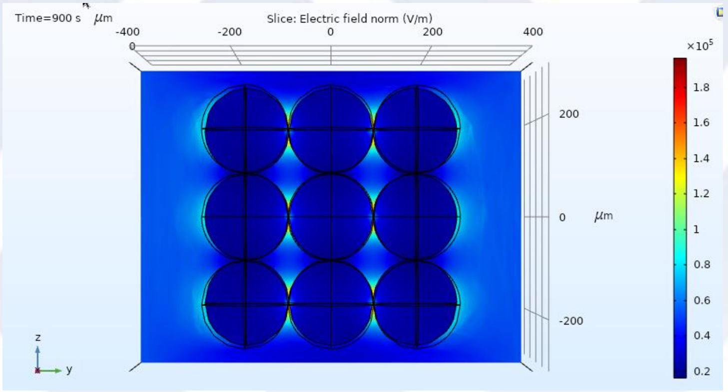
Ambient Pressure Ammonia Synthesis

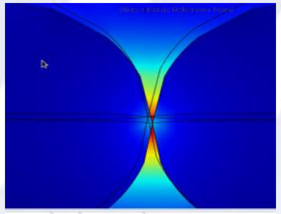
- Haber-Bosch process (3000 psig, $500^{o}C$, 1000 ton/day) difficult to scale down economically.
- Renewable power: 5 MW-100 MW, this is equivalent to 5-100 ton NH_3 per day.
- Renewable power –dealing with challenge of intermittent nature

Microwave Catalysis-Activation of N_2

Space-charge and Debye dielectric loss mechanisms for microwaves interacting with a catalyst surface for selective bond activation of reactant molecules

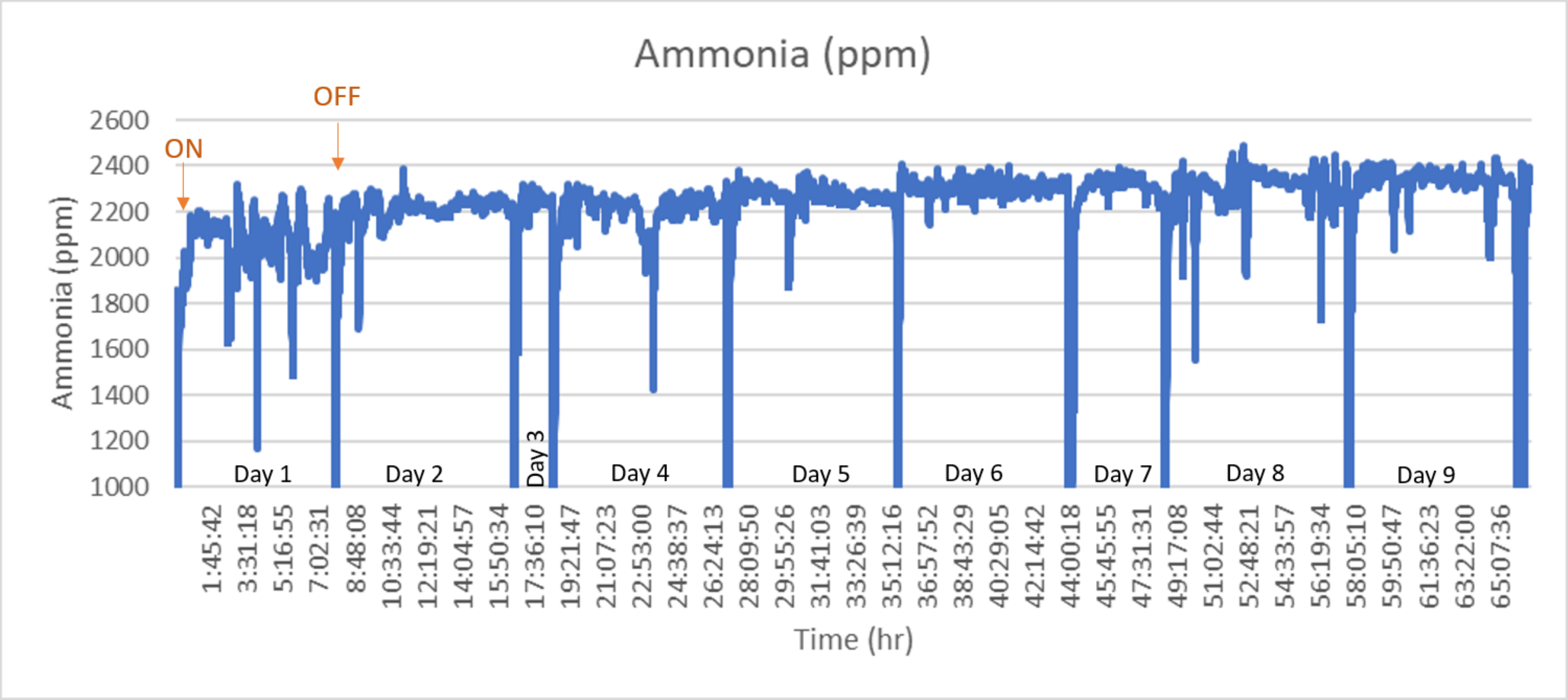






Strong e-field between particles could ionize N_2 locally

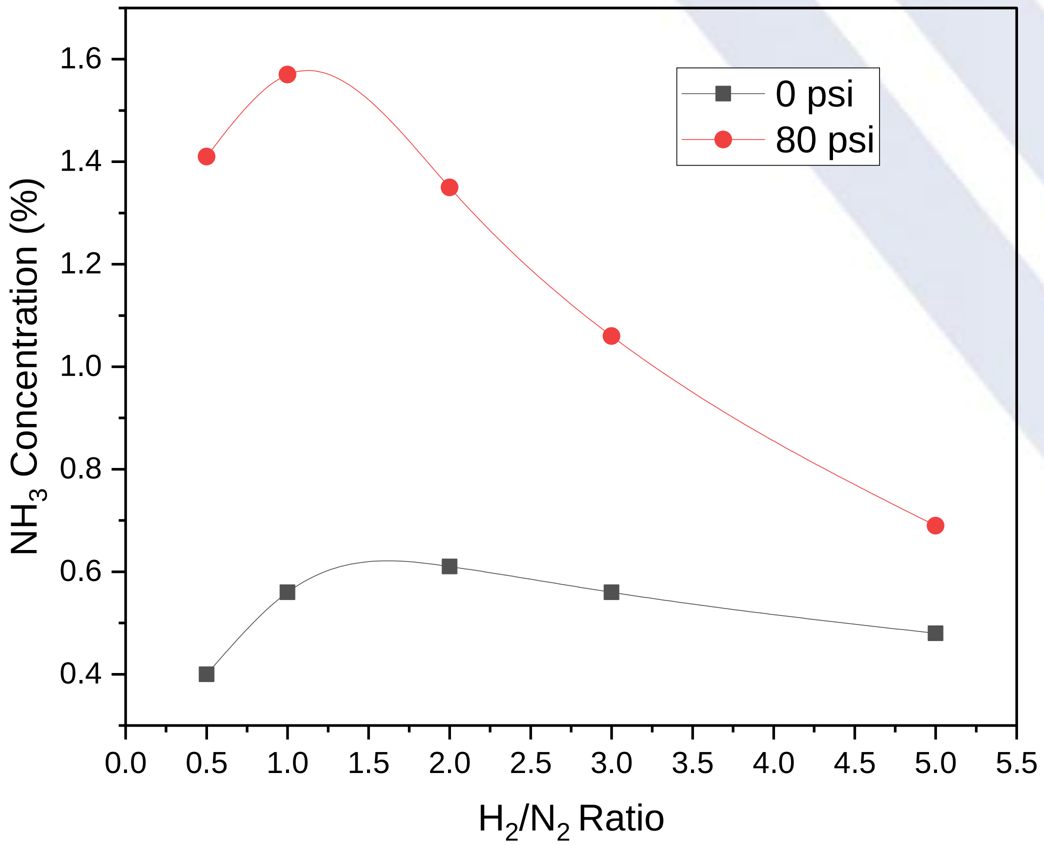
Tolerance of Intermittent Power Supply (260^{o}C, ambient Pressure)

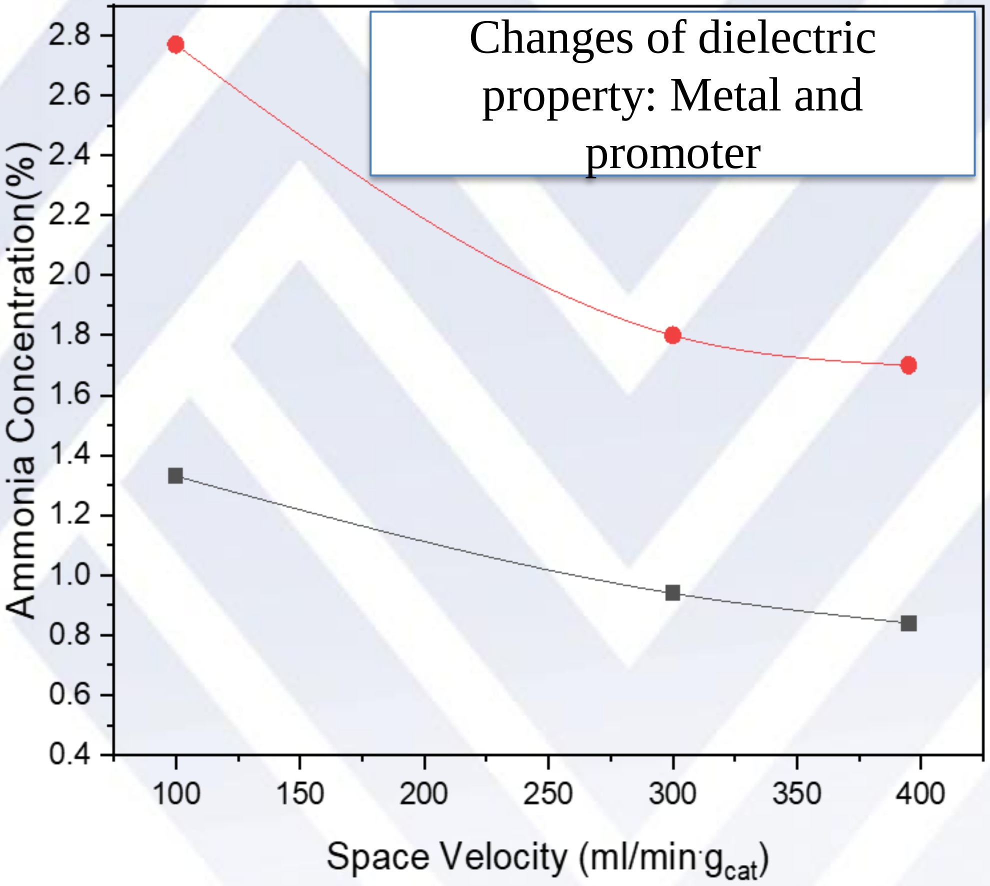


Microwave catalytic synthesis of ammonia under repeatedly startup and shutdown. During startup, reactor was back on-line within minutes. After 9 days, no performance deviation from the initial activity.

Haber Bosch: $3H_2 + N_2 = 2NH_3$

Microwave Catalysis: Pressure and H_2/N_2 Ratio (5.65 GHz, 260^{o}C)





Accomplished: ammonia production rate: 0.3 gram/gram catalyst.hr

H-Field Reactor Design- Kilograms NH_3 /day

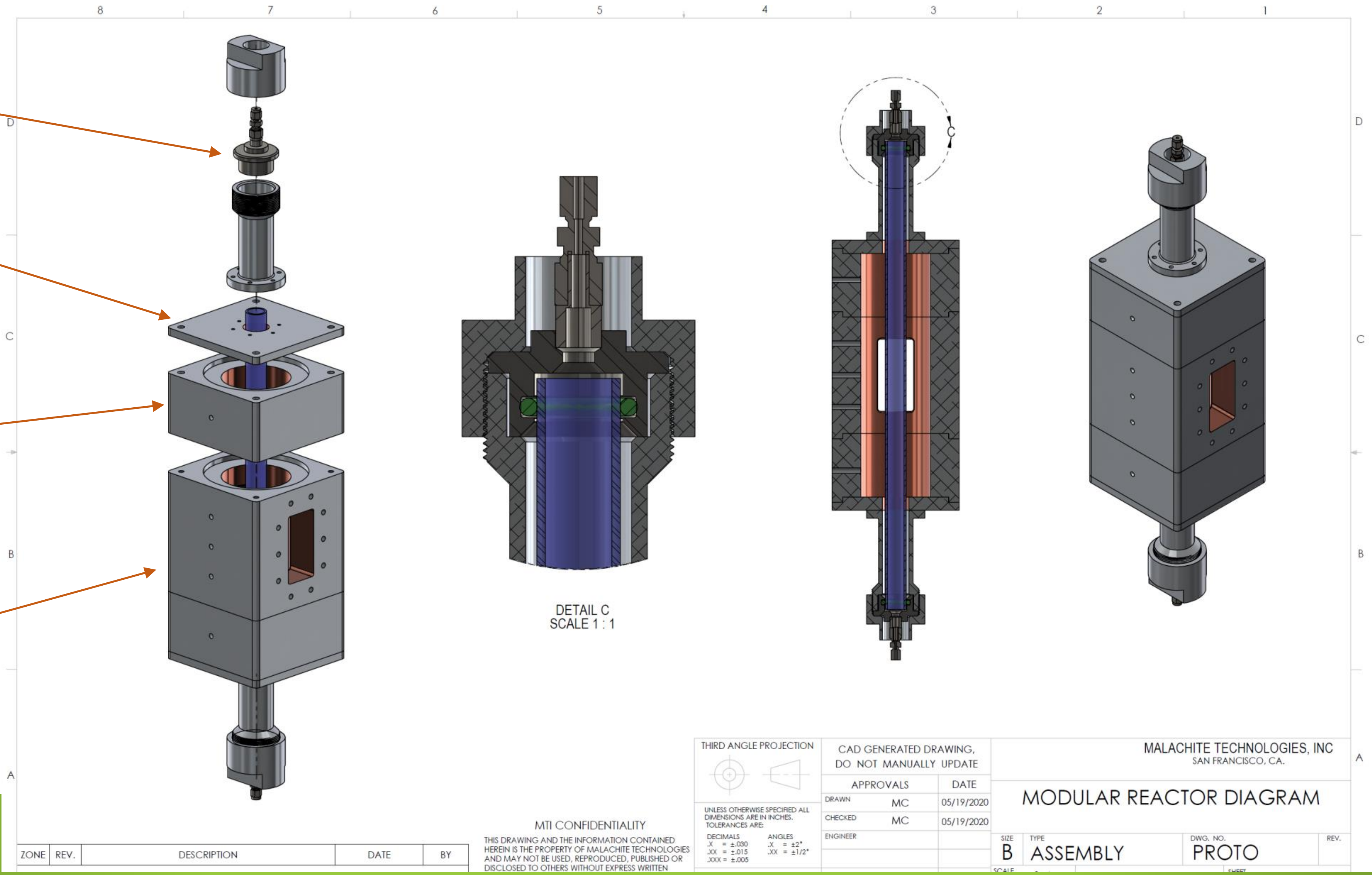
MW Choke and Pressure Cap

Design for tubes
25mmOD/19mmID
or 19mm/13.5mmID

Optional Cavity Extension with Viewport – extends length of treatment zone

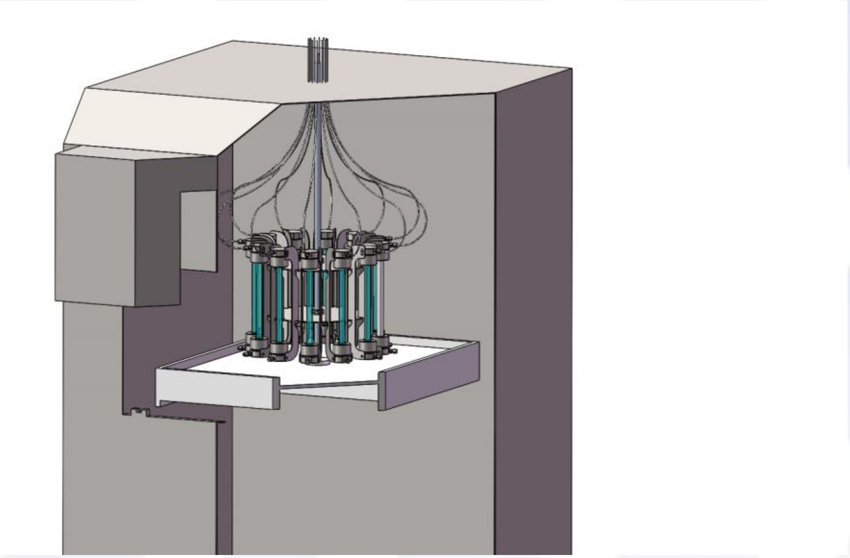
WR340 Flange Connection for H-field Cavity + 3x Viewports

+ Option to include pyrometer mount
+ Option to include E-field orientation



High Pressure Microwave Reactor

Rated: 500 psig, 1000^{o}C. The first-of-its-kind in the field



Multimode Reactor Design Concept

Simulation and Technoeconomic Analysis

Detailed MSP of the Cases

$$Minimum\ Selling\ Price\ , MSP\ NH_3\left(\frac{\$}{kWh}\right) = \frac{(AD + UC + RM)}{(PC) * LHV_{NH3} * 8000}$$

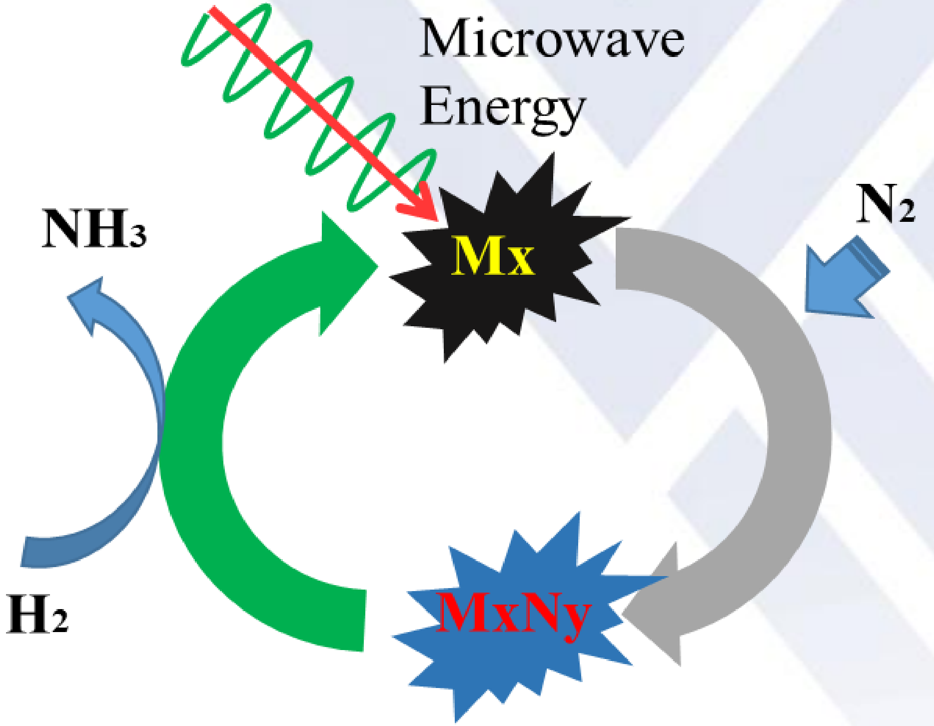
Case	RM (MM$/year)	UC (MM$/year)	AD (MM$/year)	Pressure (psig)	Single Pass H_2 Conversion (%)	MSP ($/kWh)
Case 1	24.6	6.73	6.63	80	8.08	0.123
Case 2	24.5	6.13	6.62	80	18.1	0.12
Case 3	26.0	6.72	4.51	300	10.3	0.12
Case 4	25.5	5.68	3.95	300	22.6	0.113
Case 5	26.8	6.24	3.06	500	11.4	0.117
Case 6	25.4	5.71	3.33	500	25.3	**0.111**
Case 7	24.0	5.91	2.86	500	30.8	**0.106**
Base Case 1	24.6	5.99	3.77	3970	34.1	**0.111**
Base Case 2	25.2	13.0	3.88	3970	8.08	0.136

where AD = Annualized Direct Cost
UC = Utilities Cost
RM = Raw Material Cost
PC = Plant Capacity
LHV_{NH3} = Ammonia lower heating value

- Case 1-7 has favorable MSP(MSP < $0.13/kWh)

- **Plan of the next step: 1 ton per day pilot demonstration. Forming an investable business entity**.

Future Development-Metal Nitride Reaction under Microwave



M= metals, metal alloys, perovskites

$$M_aN_{b-c} + c/2\ N_2 \longleftrightarrow M_aN_b$$

$$M_aN_b + 3c/2\ H_2 \longleftrightarrow M_aN_{b-c} + cNH_3$$

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