

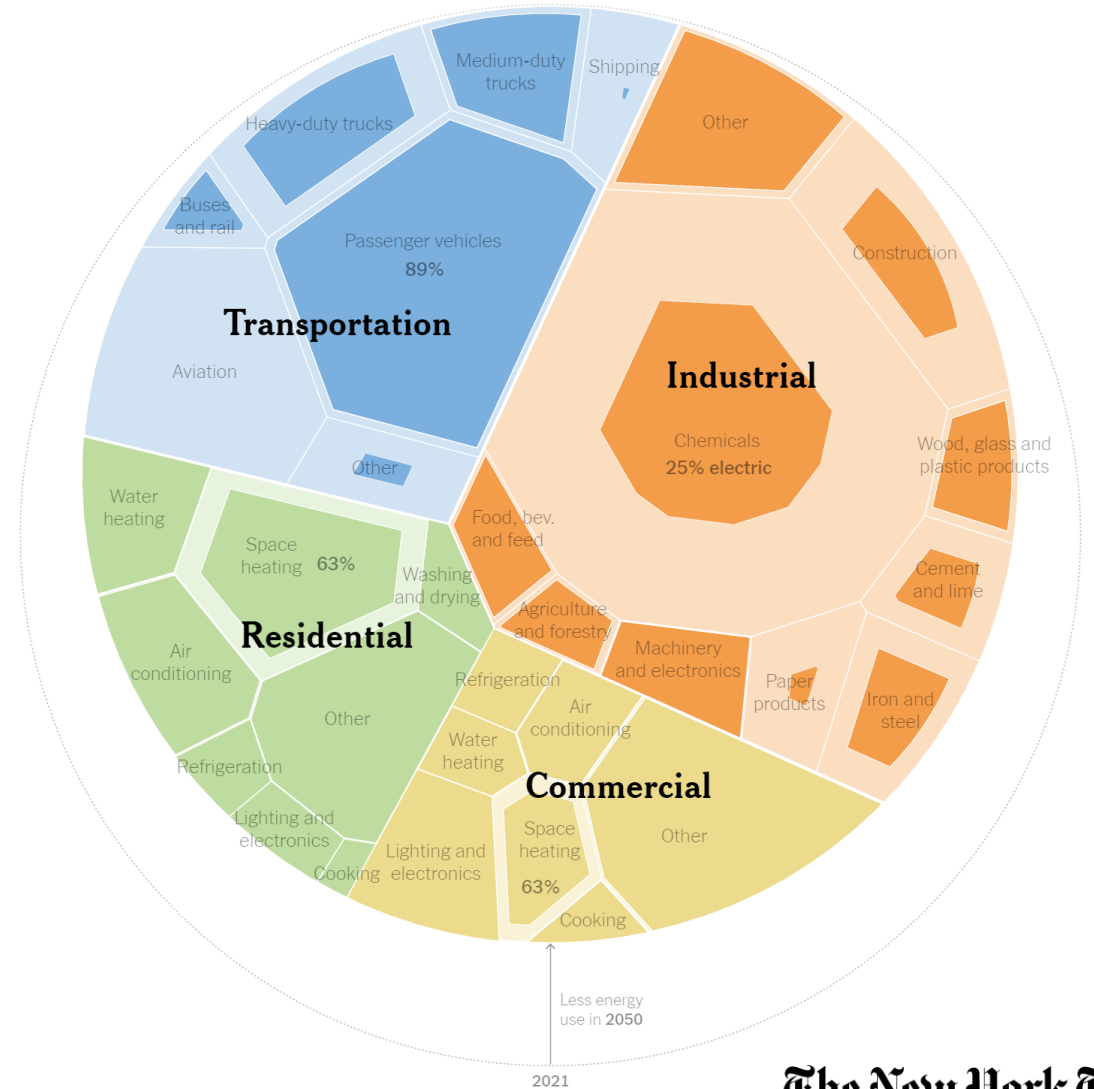
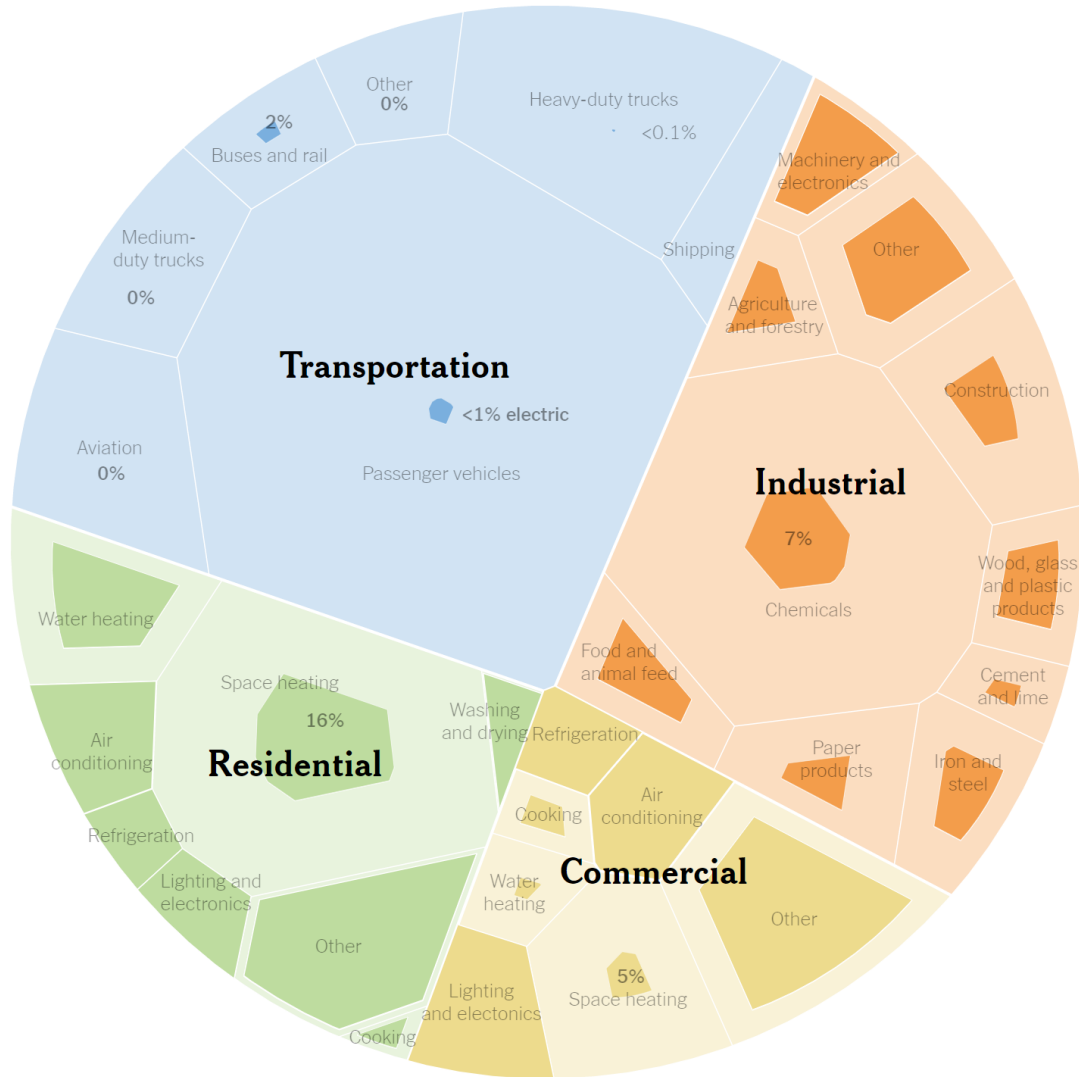
# Plasma Bubbles: A path to Green Chemistry



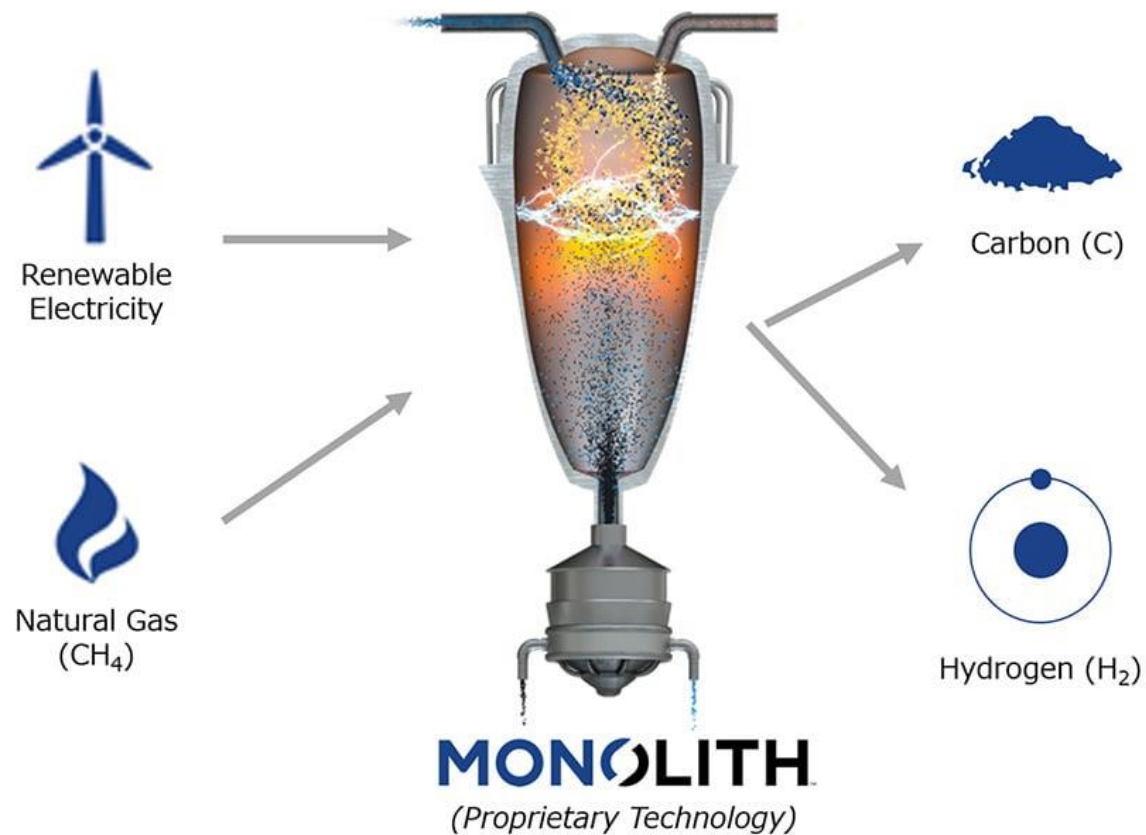
THE UNIVERSITY OF  
SYDNEY



# How electrification became a major tool for fighting climate change



# Cyan hydrogen: methane pyrolysis



**Power-to-X means using renewable electricity, for example wind power, to create something else ('X')**



## **Plasma Power-to-X (PP2X): Status and Opportunities for Non-thermal Plasma Technologies**

Jing Sun<sup>1</sup>, Zhongping Qu<sup>1</sup>, Yuting Gao<sup>1</sup>, Tianyu Li<sup>1</sup>, Tianqi Zhang<sup>2</sup>, Rusen Zhou<sup>2,23</sup>, Dingxin Liu<sup>1</sup>, Xin Tu<sup>3</sup>, Guoxing Chen<sup>4</sup>, Volker Brüser<sup>5</sup>, Klaus-Dieter Weltmann<sup>5</sup>, Danhua Mei<sup>6</sup>, Zhi Fang<sup>6</sup>, Ana Borrás<sup>7</sup>, Angel Barranco<sup>7</sup>, Shaojun Xu<sup>8</sup>, Chuanlong Ma<sup>9</sup>, Liguang Dou<sup>10</sup>, Shuai Zhang<sup>10</sup>, Tao Shao<sup>10</sup>, Guangliang Chen<sup>11</sup>, Dawei Liu<sup>12</sup>, Xinpei Lu<sup>12</sup>, Zheng Bo<sup>13</sup>, Wei-Hung Chiang<sup>14</sup>, Krasimir Vasilev<sup>15</sup>, Michael Keidar<sup>16</sup>, Anton Nikiforov<sup>17</sup>, Ali Rouhollah Jalili<sup>18</sup>, Patrick J. Cullen<sup>2,18</sup>, Liming Dai<sup>19</sup>, Volker Hessel<sup>20</sup>, Annemie Bogaerts<sup>21</sup>, Anthony B. Murphy<sup>22</sup>, Renwu Zhou<sup>1\*</sup>, Kostya (Ken) Ostrikov<sup>23</sup>

<sup>1</sup> State Key Laboratory of Electrical Insulation and Power Equipment, Centre for Plasma Biomedicine, School of Electrical Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, People's Republic of China

<sup>2</sup> School of Chemical and Biomolecular Engineering, University of Sydney, Sydney, NSW 2006, Australia

<sup>3</sup> Department of Electrical Engineering and Electronics, University of Liverpool, Liverpool L69 3GJ, UK

<sup>4</sup> Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS, Brentanostraße 2a, 63755 Alzenau, Germany

<sup>5</sup> Leibniz Institute for Plasma Science and Technology, INP Greifswald e.V., 17489 Greifswald, Germany

<sup>6</sup> College of Electrical Engineering and Control Science, Nanjing Tech University, Nanjing, Jiangsu 211816, People's Republic of China

<sup>7</sup> Nanotechnology on Surfaces and Plasma Laboratory, Materials Science Institute of Seville, CSIC-US, C/Americo Vespucio 49, 41092, Seville, Spain

<sup>8</sup> School of Electrical and Automation Engineering, Hefei University of Technology, Hefei 230009, China

<sup>9</sup> Catalytic and Plasma Process Engineering, Department of Chemical Engineering, McGill University,

# PLASMA BUBBLES



# AMMONIA

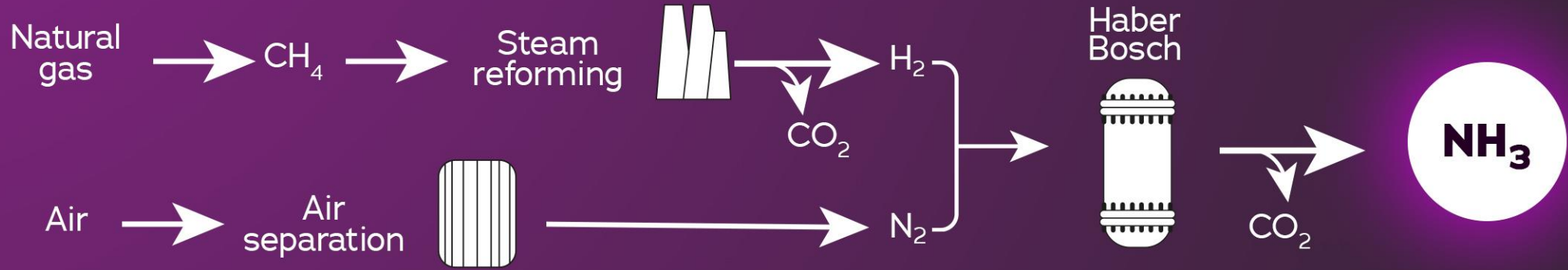


# HISTORY

**Birkeland–Eyde (1903):** used electrical arcs (thermal plasma) to react atmospheric nitrogen ( $N_2$ ) with oxygen ( $O_2$ ), ultimately producing nitric acid ( $HNO_3$ ) with water.

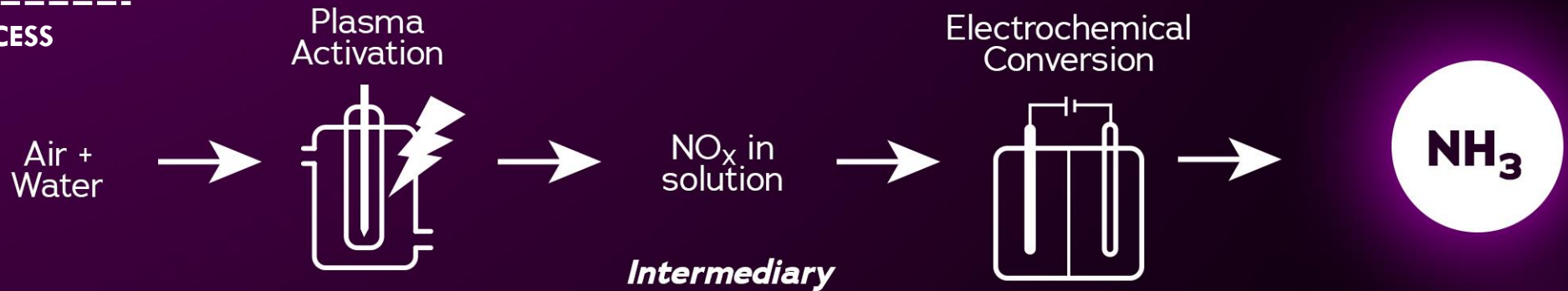
RJUKAN FAB. ANL. II. 606. OVNŠHUS, 4-8-15.

# HABER-BOSCH GREY AMMONIA

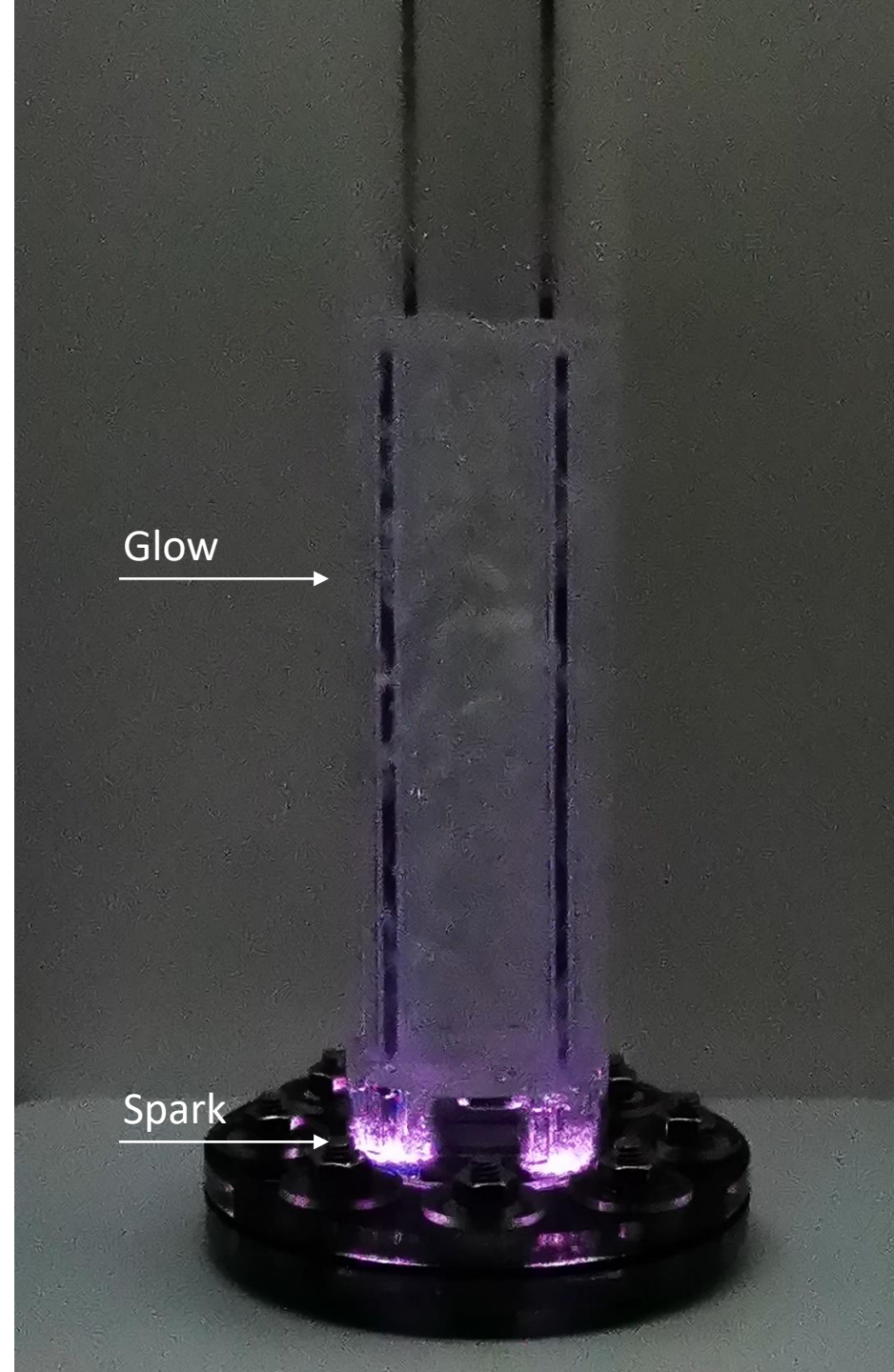
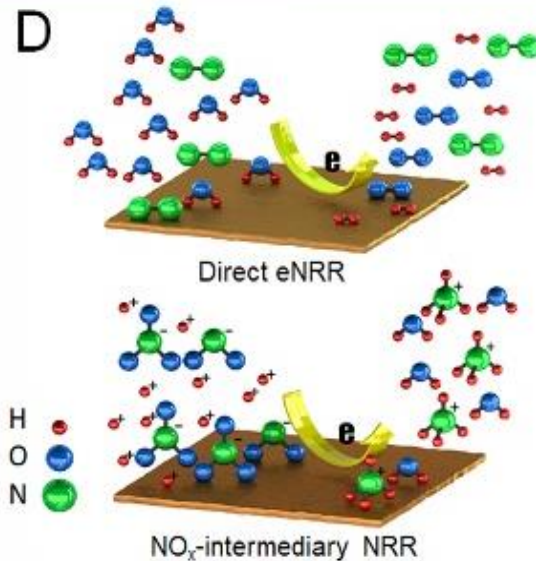
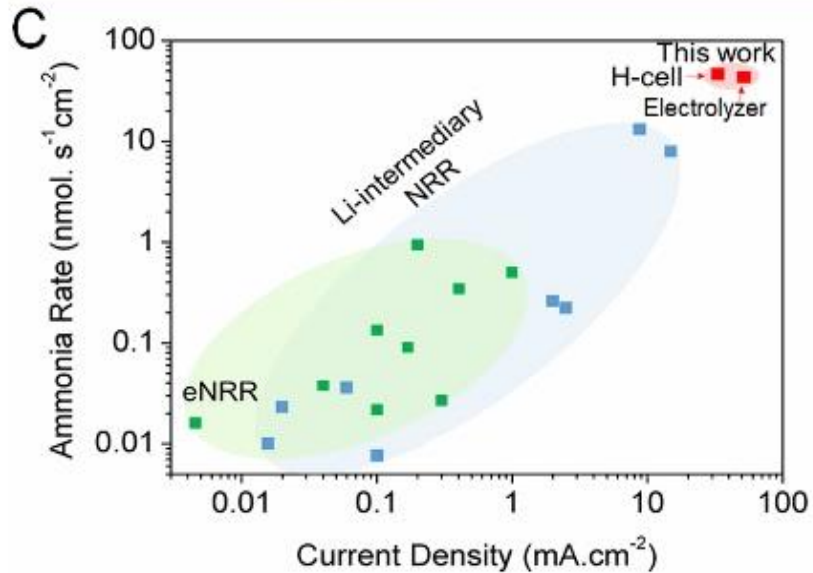
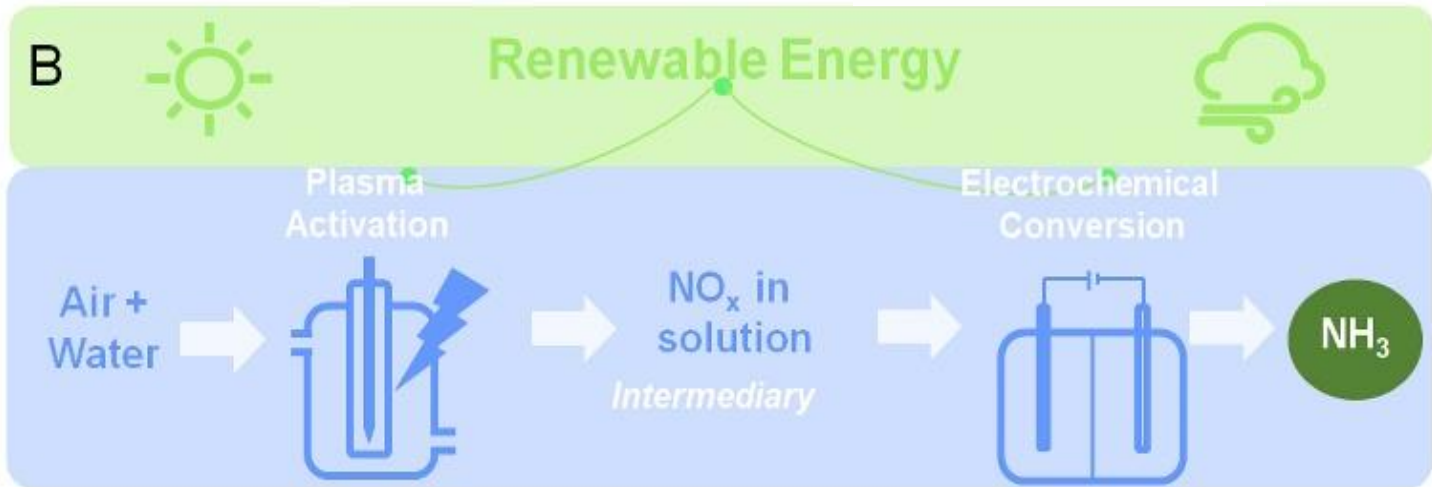


# PLASMALEAP GREEN AMMONIA

## PLASMA BUBBLE PROCESS



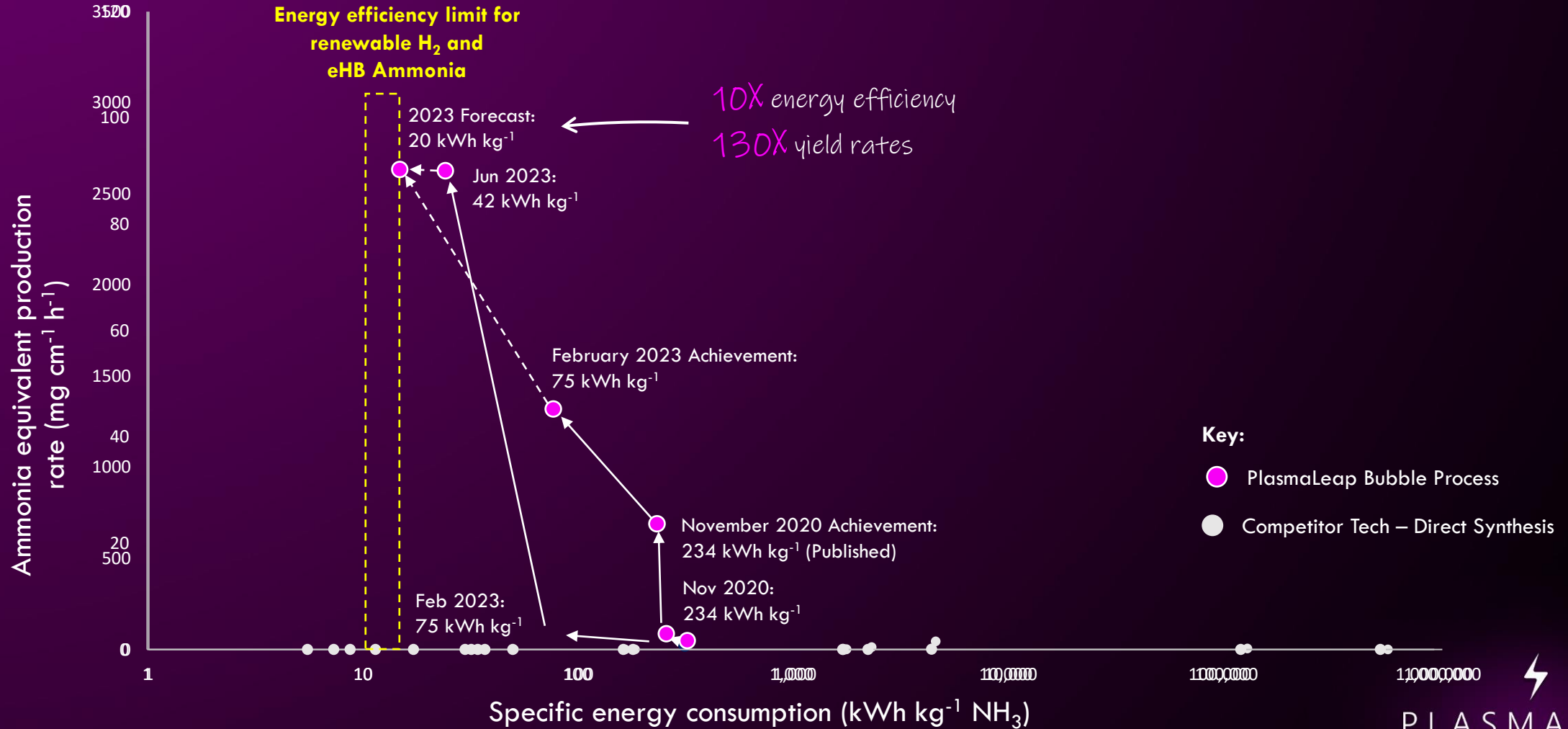




A hybrid plasma electrocatalytic process for sustainable ammonia production. *Energy & Environmental Science*, (2021) 14(2), 865-872.

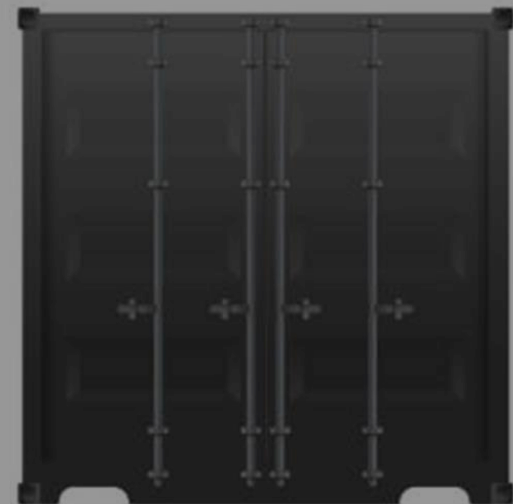
# MARKET LEADING PERFORMANCE

We are on track to combining world leading energy efficiency & production rates



Graph: Zero-emission Direct Ammonia Synthesis Performance, Source: PlasmaLeap

# NITRATES / AMMONIA MODULAR BASE UNIT

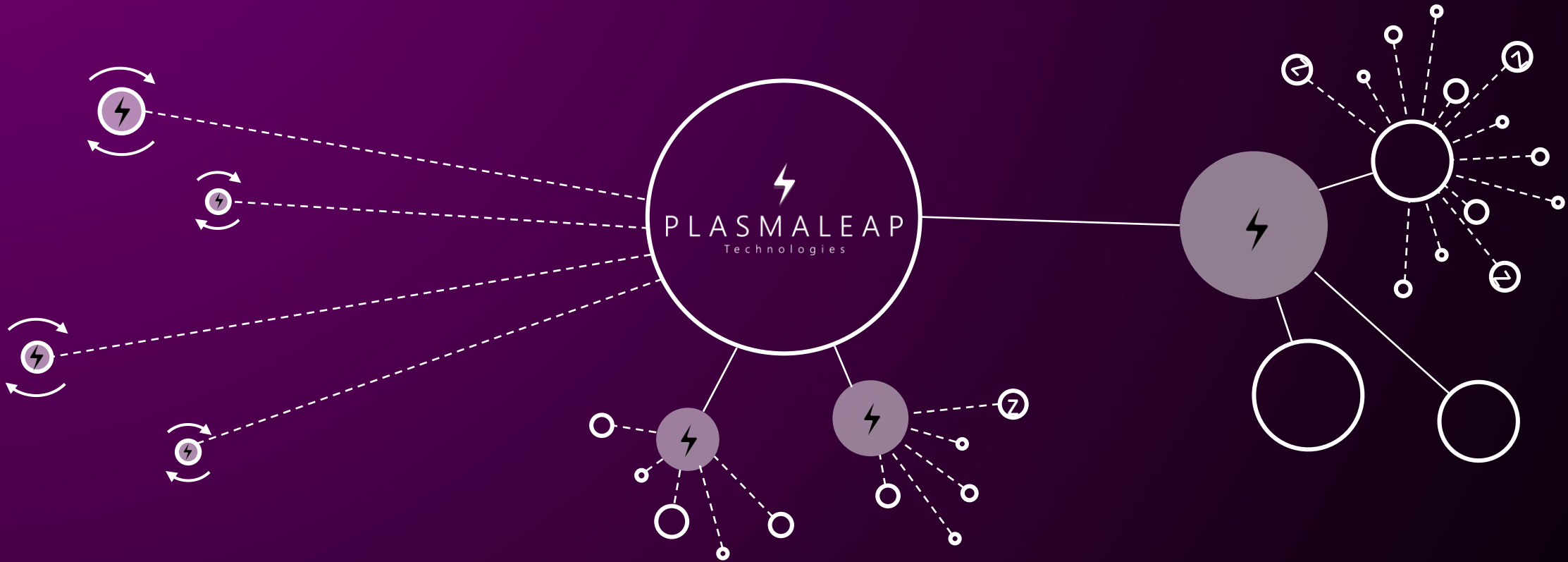


• Launch 2024



PLASMA-DRIVEN-POWER-2-X

# OUR COMMERCIAL ROADMAP



2024  
Decentralized Production  
On-Farm Nitrate Units  
100-200t p.a.



2026  
Semi-centralized Production  
Regional Ammonia Hubs  
1-5 Kt p.a.

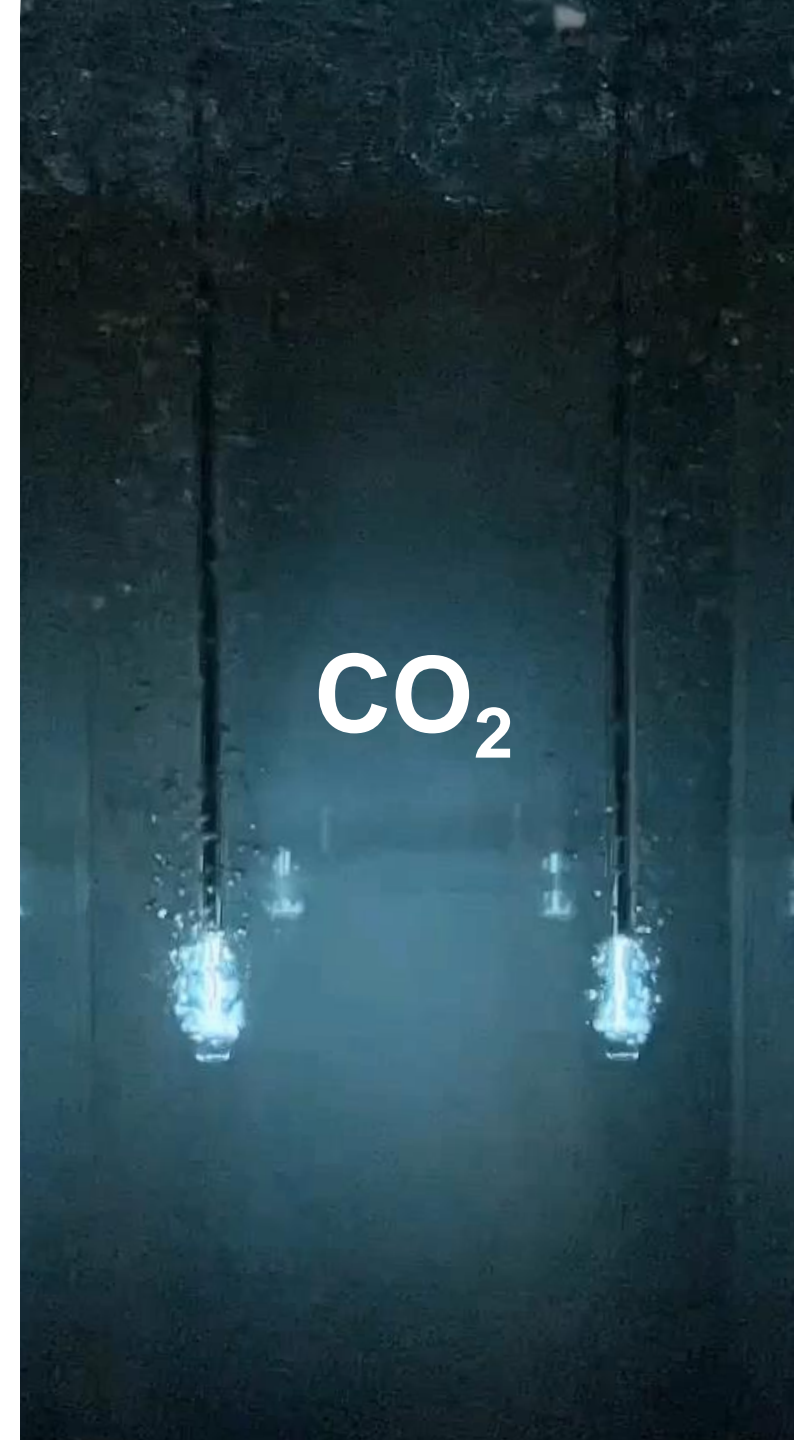
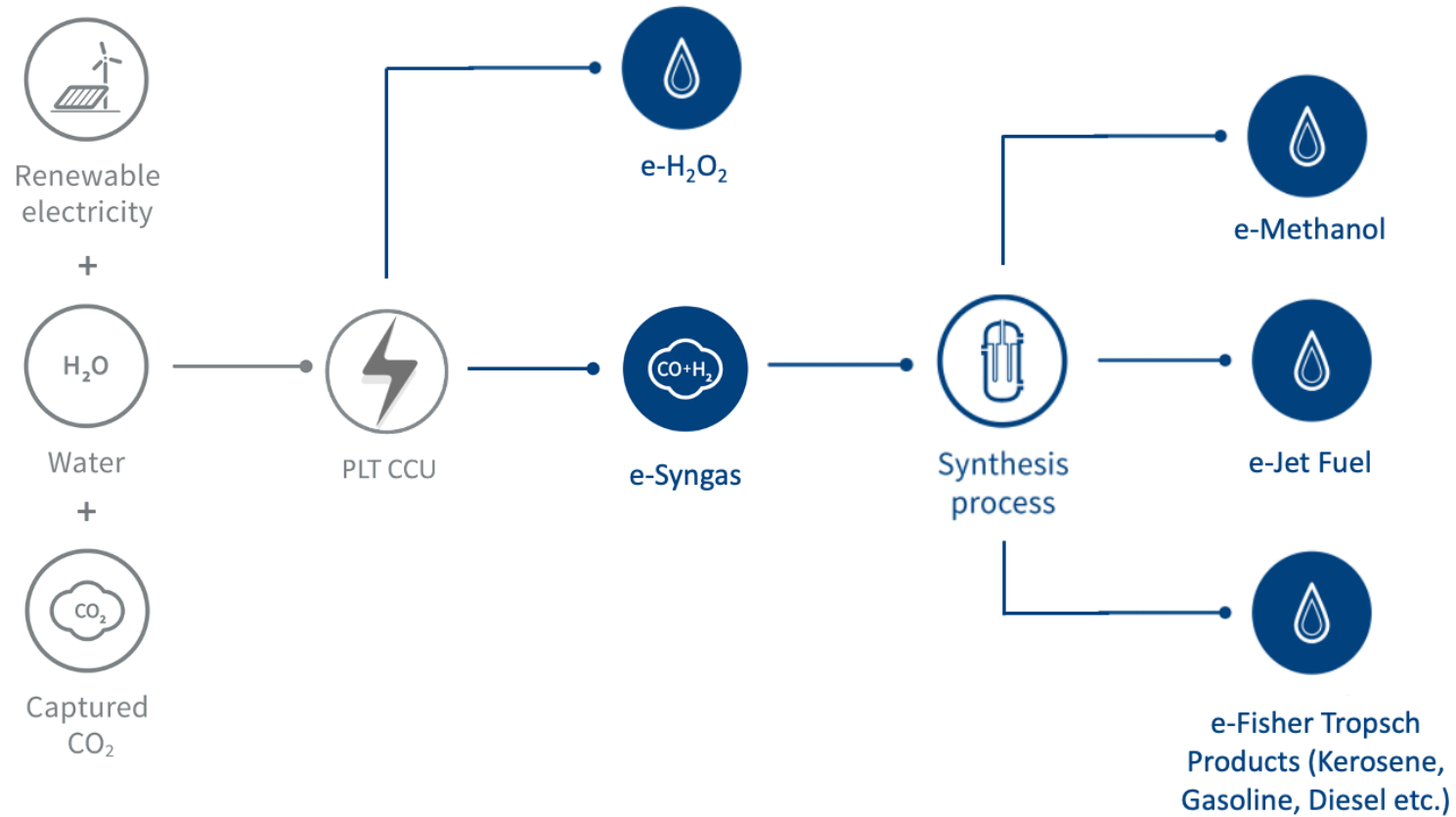


2030  
Centralized Production  
Large-scale Ammonia Plants  
500kt - 1Mt+ p.a.



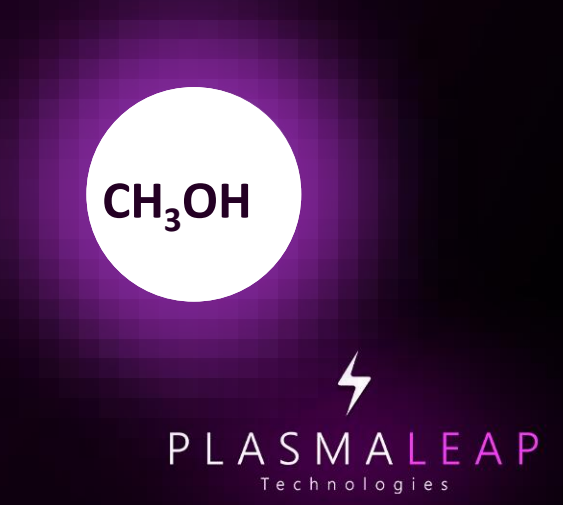
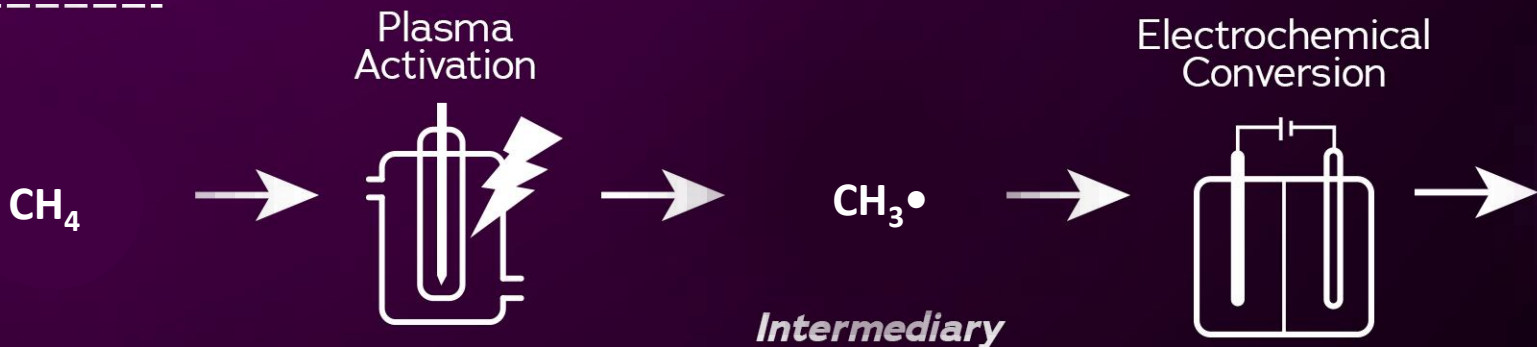
# METHANOL

# eFuels



# HYBRID ELECTROCATALYSIS

---

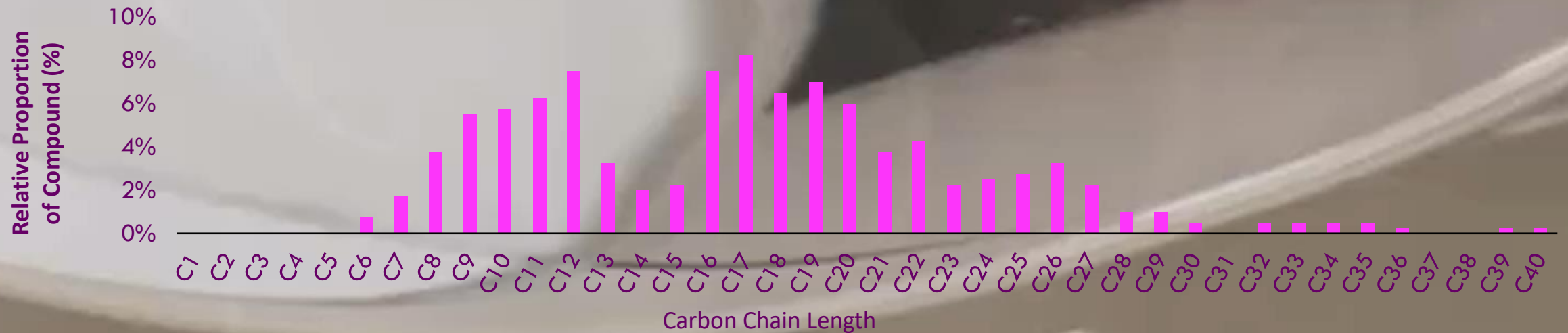




# HYDROCARBON eFUELS



THE UNIVERSITY OF  
SYDNEY



# Plasma chemistry modelling

- Provide information on important pathway to utilize the reactants and produce target products through sensitivity analysis on different reactions in gas phase, on surface and water volume

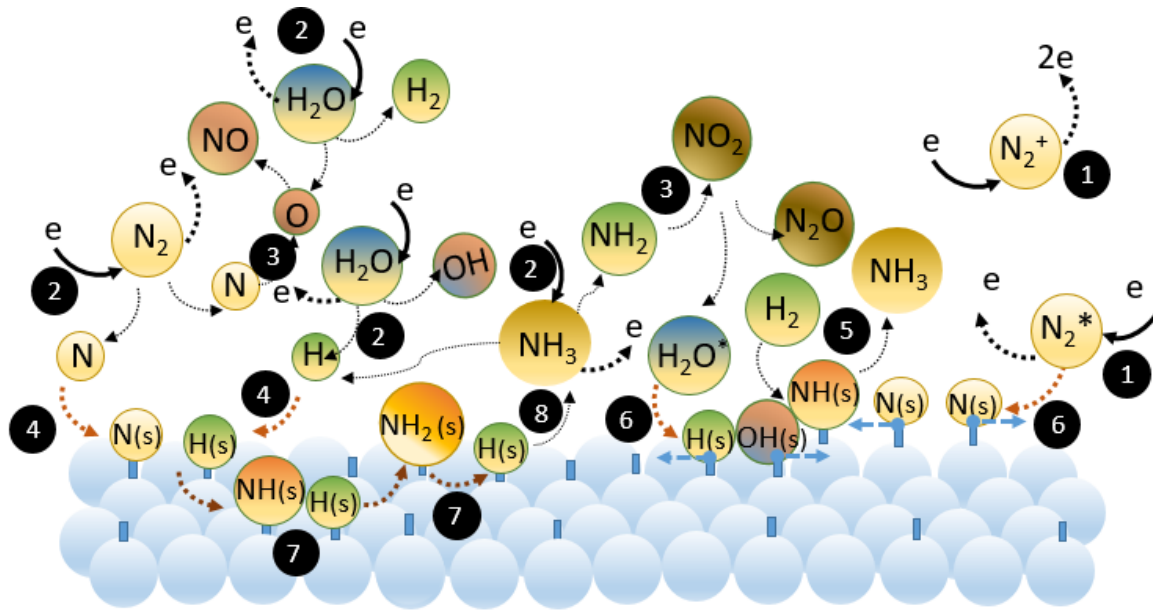
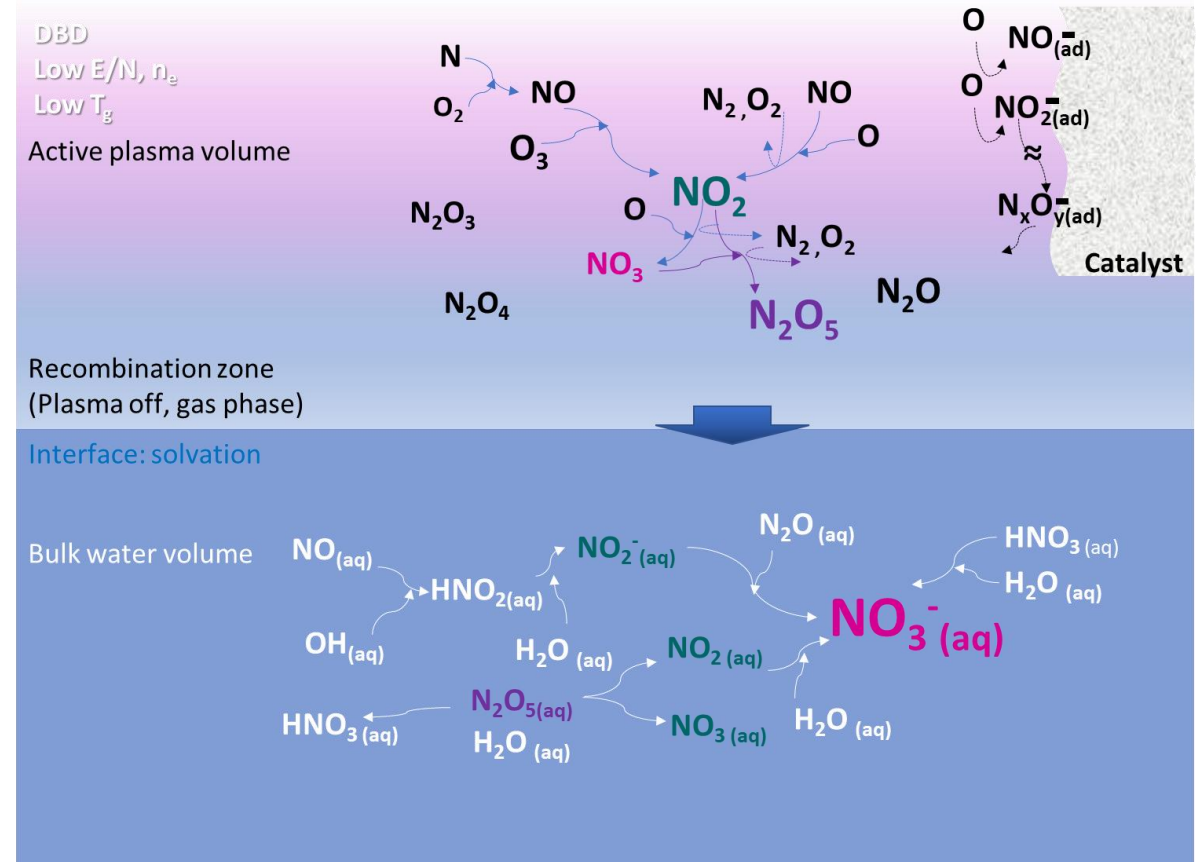


Illustration on possible pathway of plasma synthesis of  $\text{NH}_3$  in  $\text{N}_2/\text{H}_2\text{O}$  system

Hong et al. Green Chem., (2022) 24, 7458

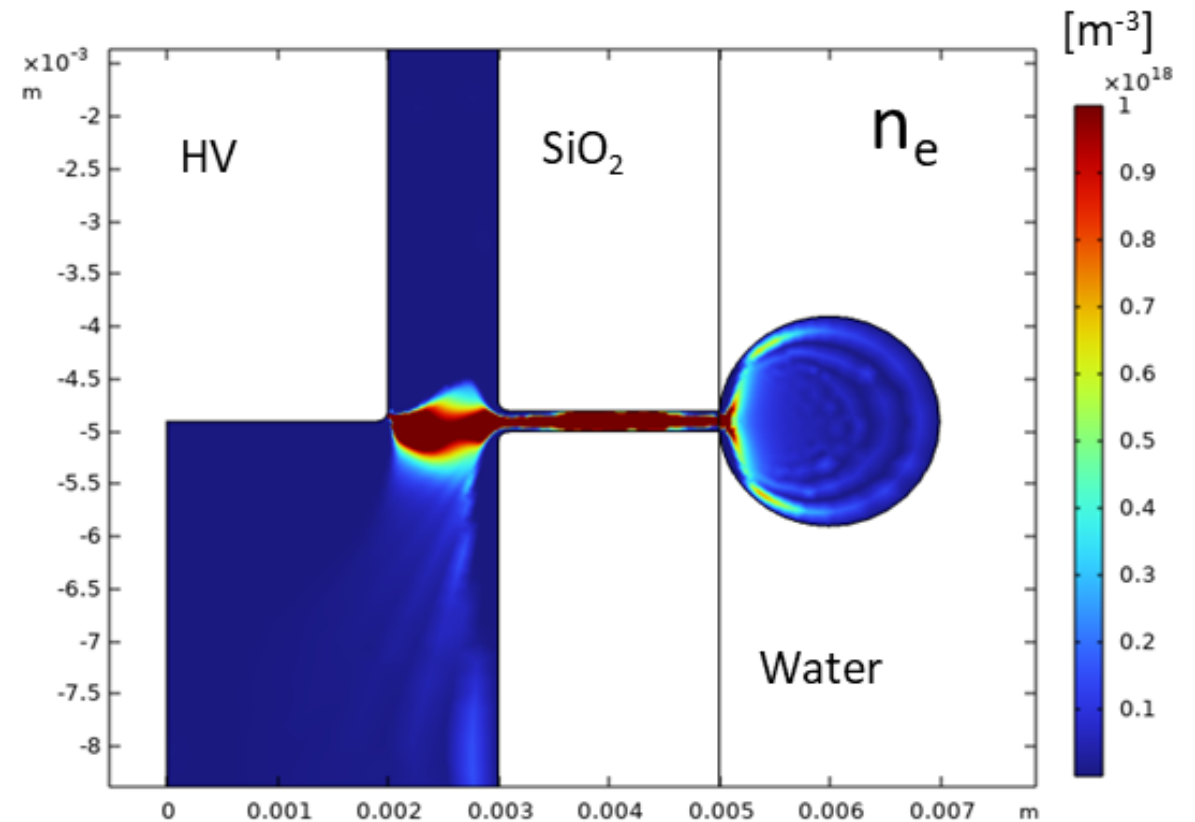
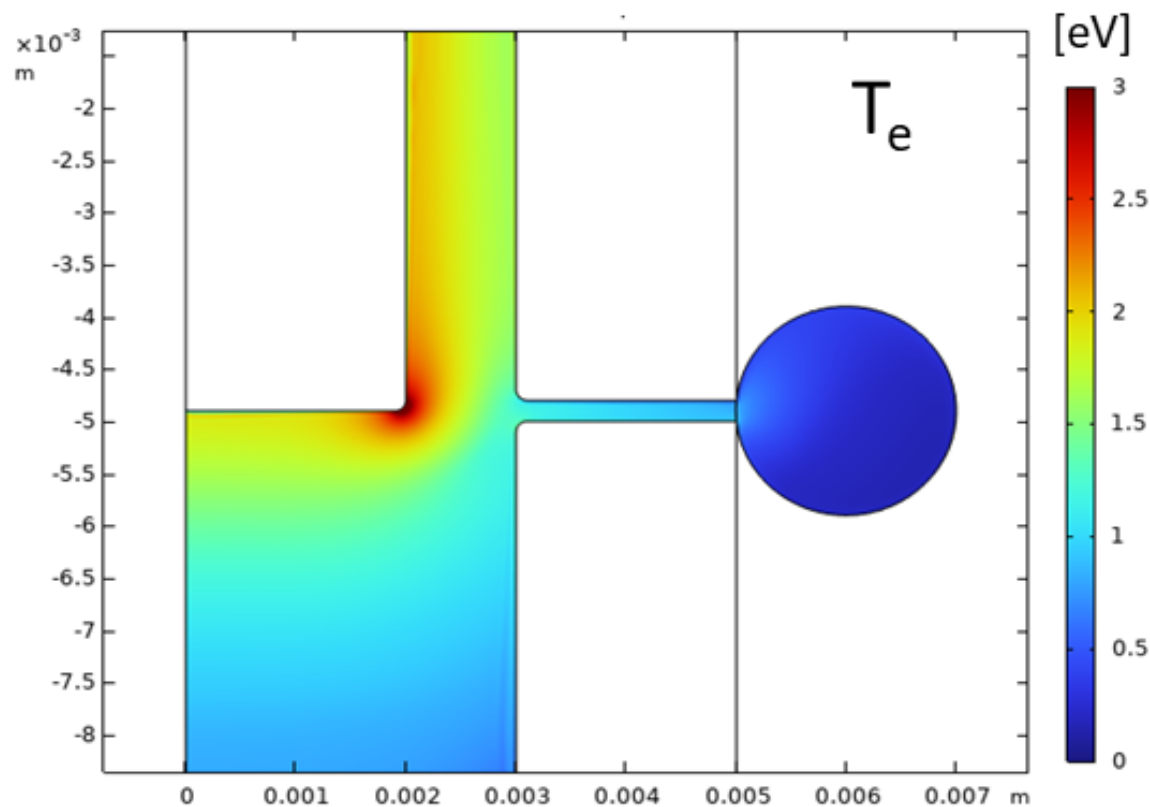


Suggested mechanism of  $\text{NO}_x$  production in DBD plasma

Sun et al. Chem. Eng. J. (2023) 469, 143841

# Plasma fluid modelling

- Aim to extend to Multi-phase, Multi-physics computational study to improve understanding on the actual complex nature of plasma interaction



Thank you