# Ionic Liquids as Safe, Energy-Dense Electrochemical Fuels

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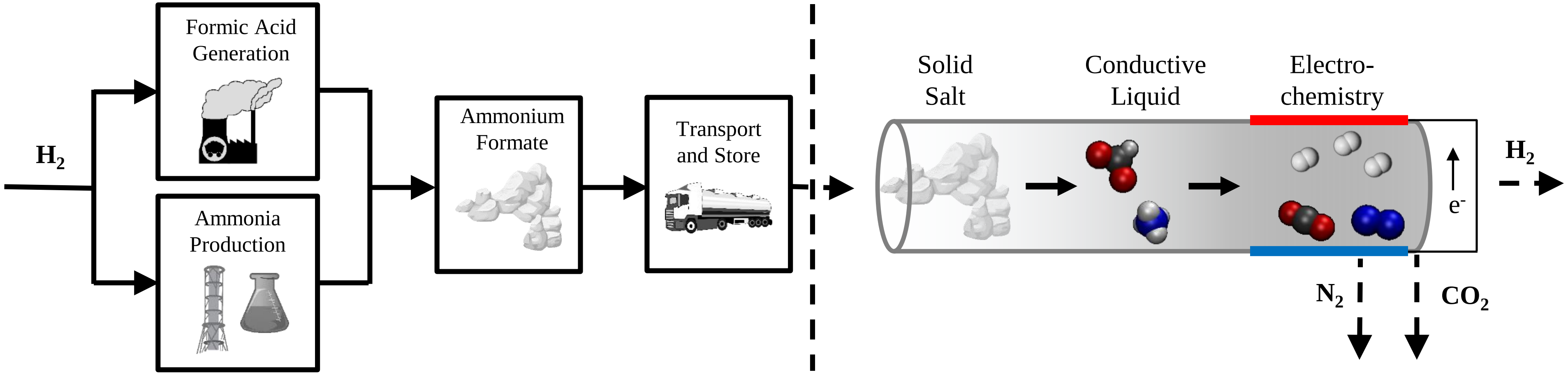
# A need for the ideal renewable energy carrier

| Energy Carrier | Volumetric Energy Density (kWh/L)[1] | Easy and cheap to produce | High energy content | Cheap and safe transport and storage | Efficient energy extraction |
|---|---|---|---|---|---|
| Li-ion Battery | 0.2-0.7 | ✓ | ✗ | ✓ | ✓ |
| Liquid $H_2$ | 2.3 | ✓ | ✓ | ✗ | ✓ |
| Liquid Ammonia | 4.3 | ✓ | ✓ | ✓ | ✗ |
| Formic Acid | 1.8 | ✓ | ✓ | ✓ | ✗ |
| Ammonium Formate[2] | 4.5 | ✓ | ✓ | ✓ | ✗ |

# Paradigm: ammonium formate as energy carrier

*Safe, easily transported solid*

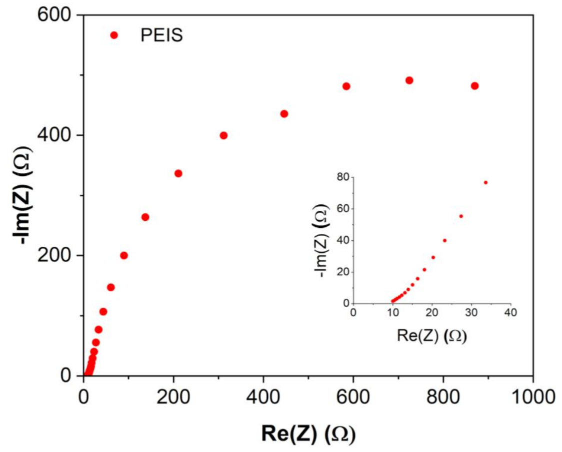


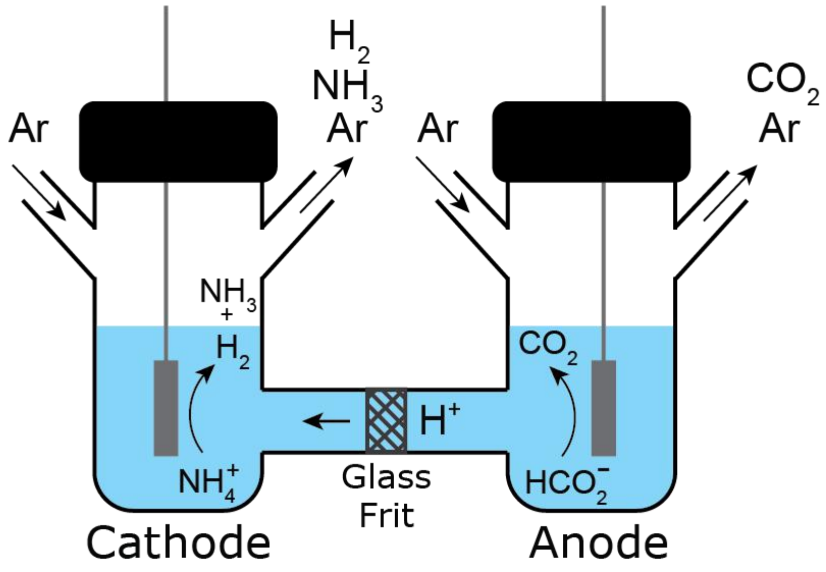

Ammonium Formate is combination of formic acid and ammonia
Forms ionic liquid at 116°C, meaning entire electrolyte is fuel

# Electrochemical setup and product analysis

Electrochemical cell with
liquid ammonium formate

**Electrochemical analysis:**
*Impedance*
*Cyclic voltammograms*
*Chronoamperometry*



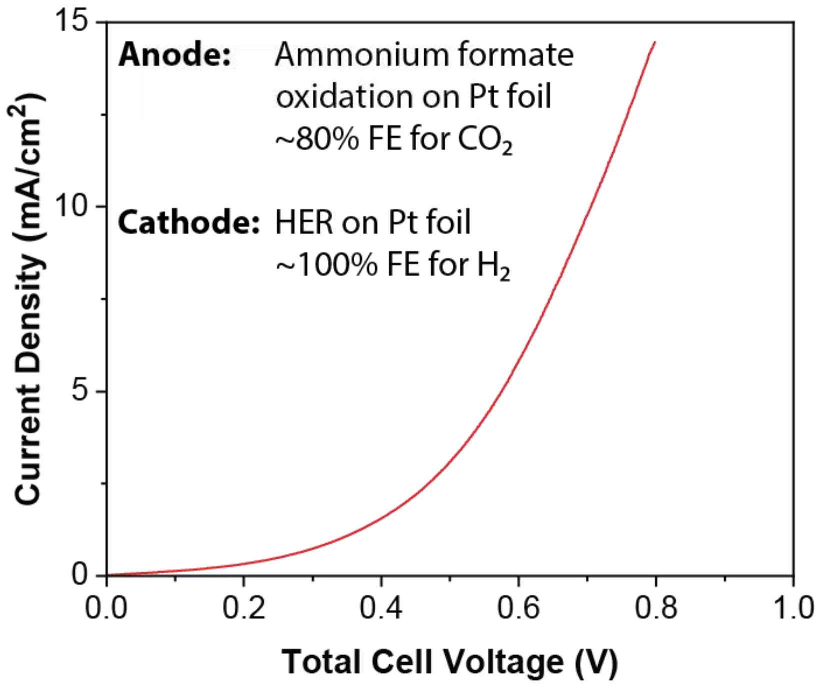




**Product analysis:**
*Gas chromatography*
*NMR*
*Colormetric assays*

# Successful electrochemical $H_2$ extraction

**Cathode**

$$NH_4^+ + e^- \rightarrow NH_3 + \frac{1}{2}H_2$$




**Anode**

$$2HCO_2^- \rightarrow CO_2 + HCOOH + 2e^-$$

**Future Work**

Currently only oxidizing formate

Additives and cell engineering will allow for complete fuel oxidation

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# Acknowledgments & Questions


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Manthiram Lab:

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NSF

GRFP
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J-WAFS


@ManthiramLab

# References

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Aoki, H.; Nitta, T.; Kuwabata, S.; Kimura, C.; Sugino, T. *ECS Trans.* **2008**, *16* (2), 849–853

Ohyama, K.; Kimura, C.; Aoki, H.; Kuwabata, S.; Sugino, T. *ECS Trans.* **2007**, *11* (1), 1473–1477.

# Backup Slides

# Paradigm: ammonium formate as energy carrier

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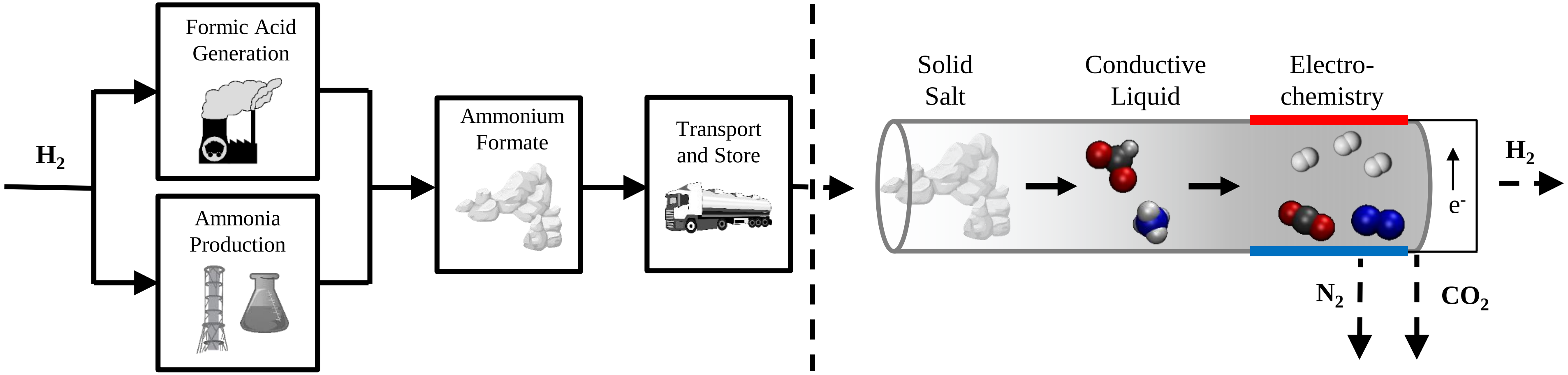
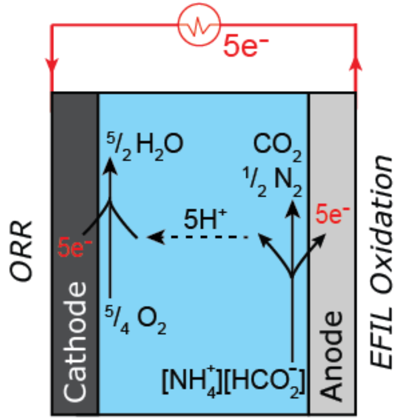
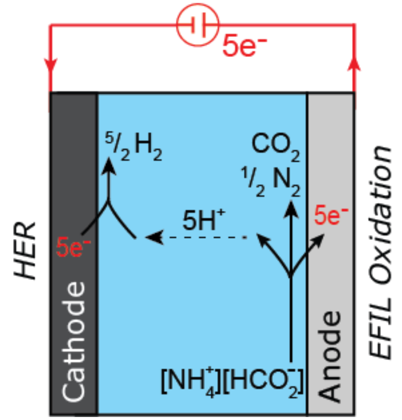



Extract *electricity*




vs.

Extract *hydrogen*

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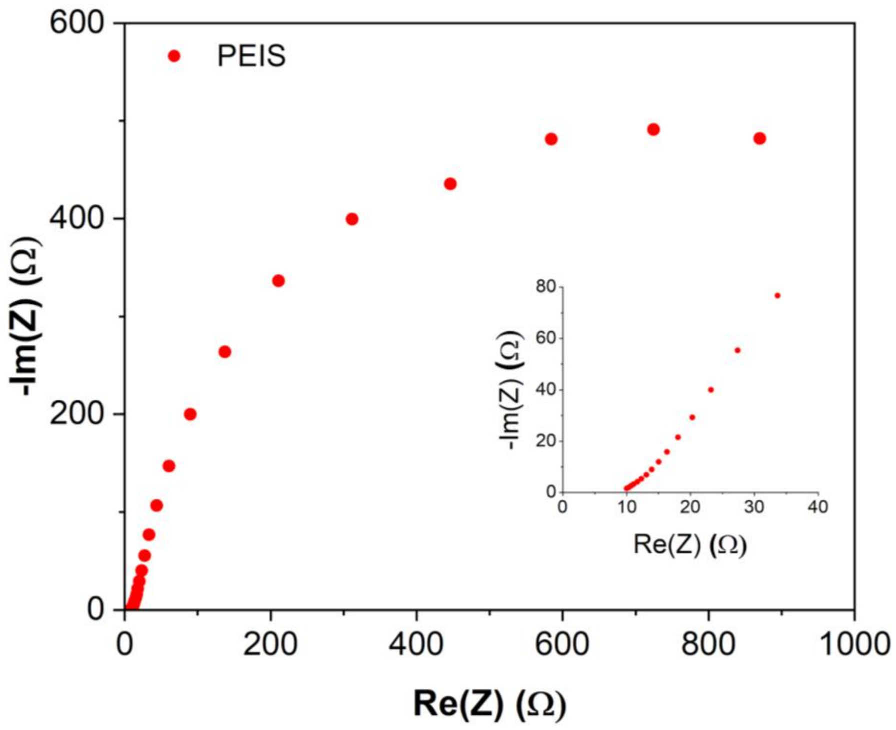
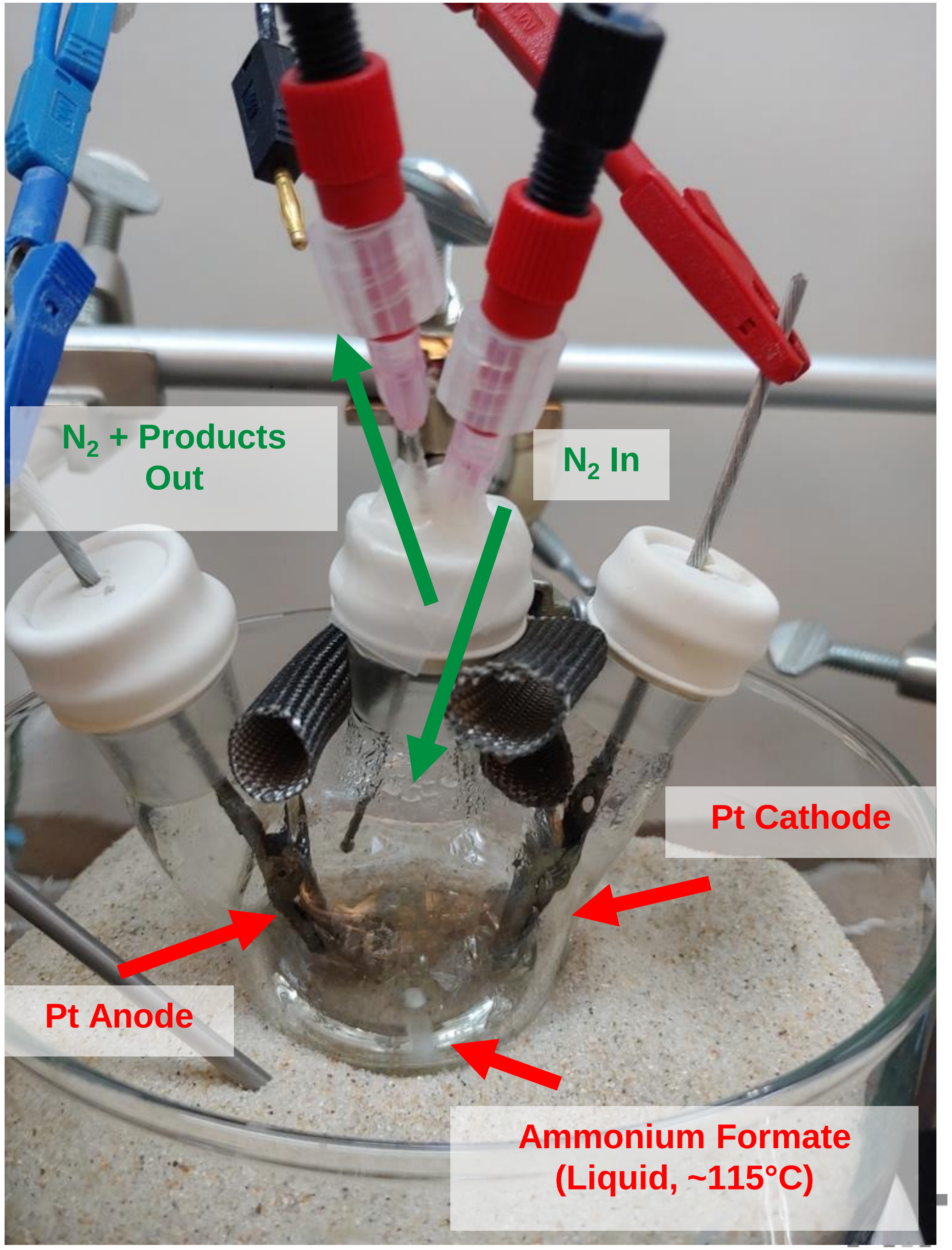
# Experimental System

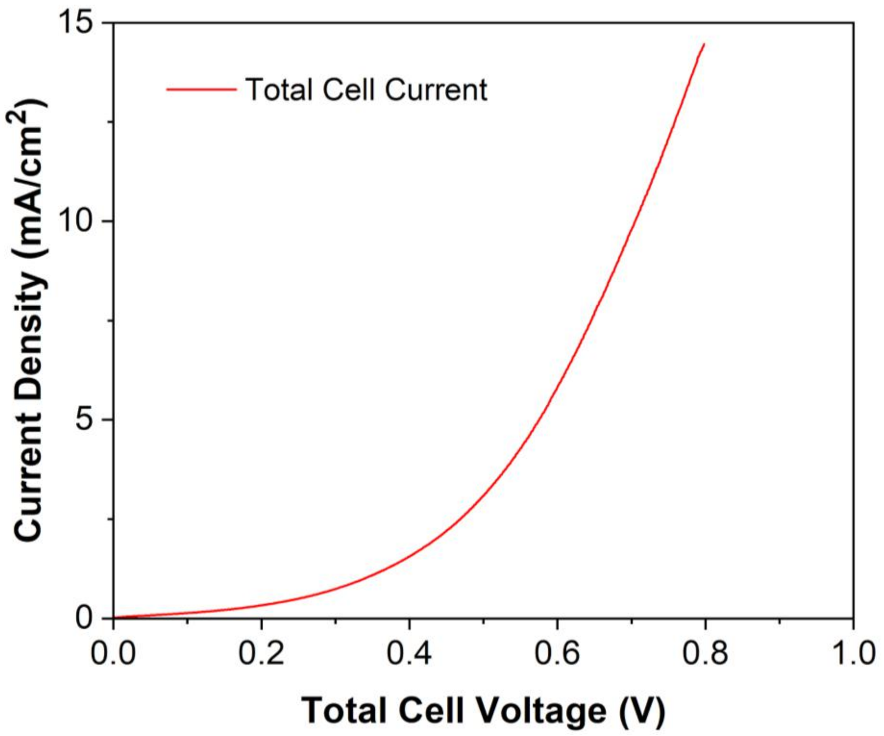
ILs are conductive



# Experimental System

OCV predicted to be 0.04 V

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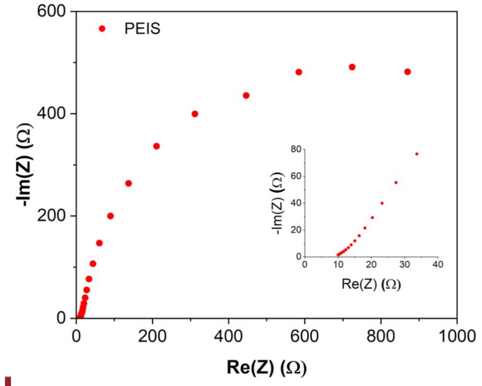
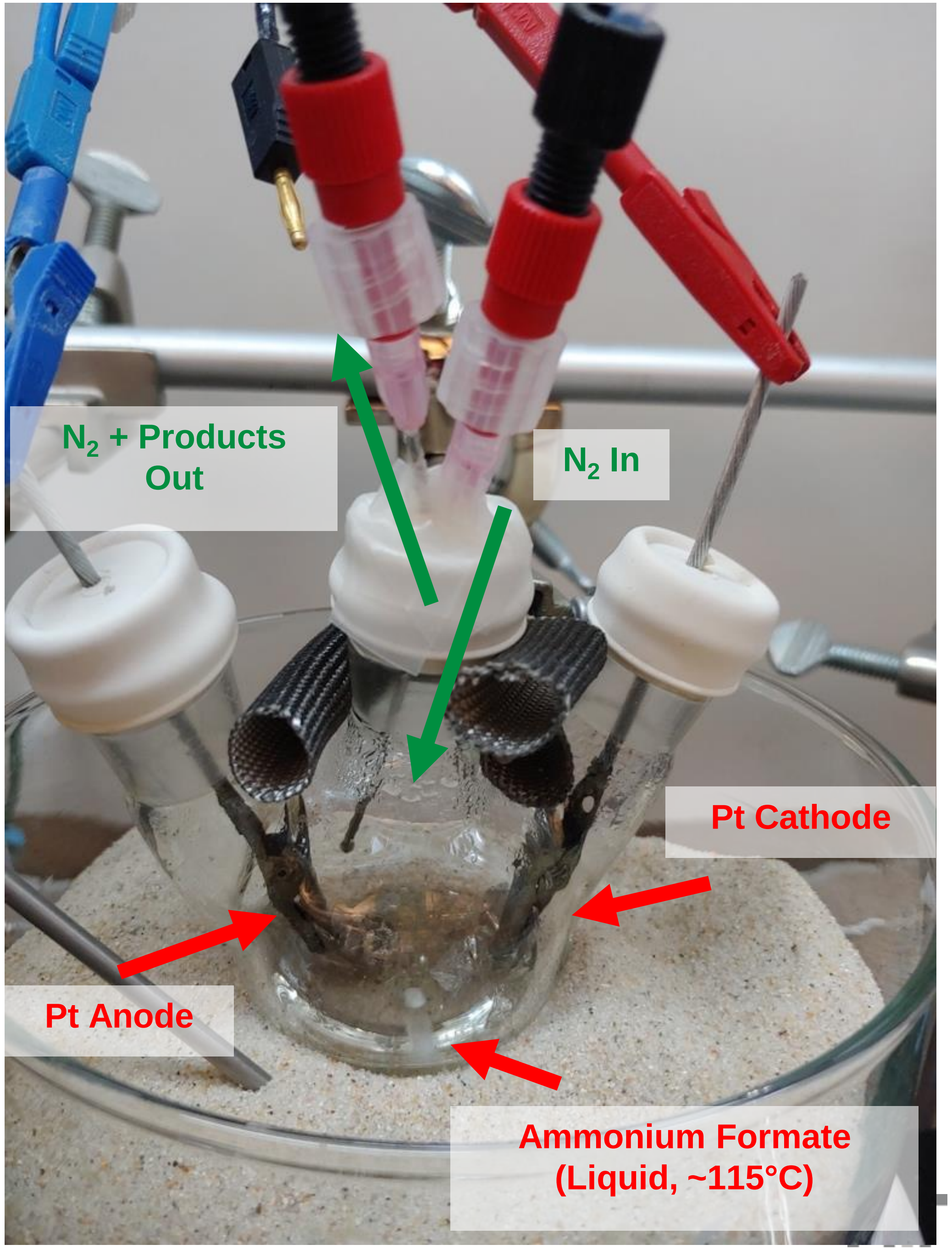


# Ammonium Formate Decomposition

**Anode**

| Current (mA) | FE toward $CO_2$ |
|---|---|
| 1 | 104% |
| 3 | 77% |
| 5 | 58% |
| 6 | 86% |

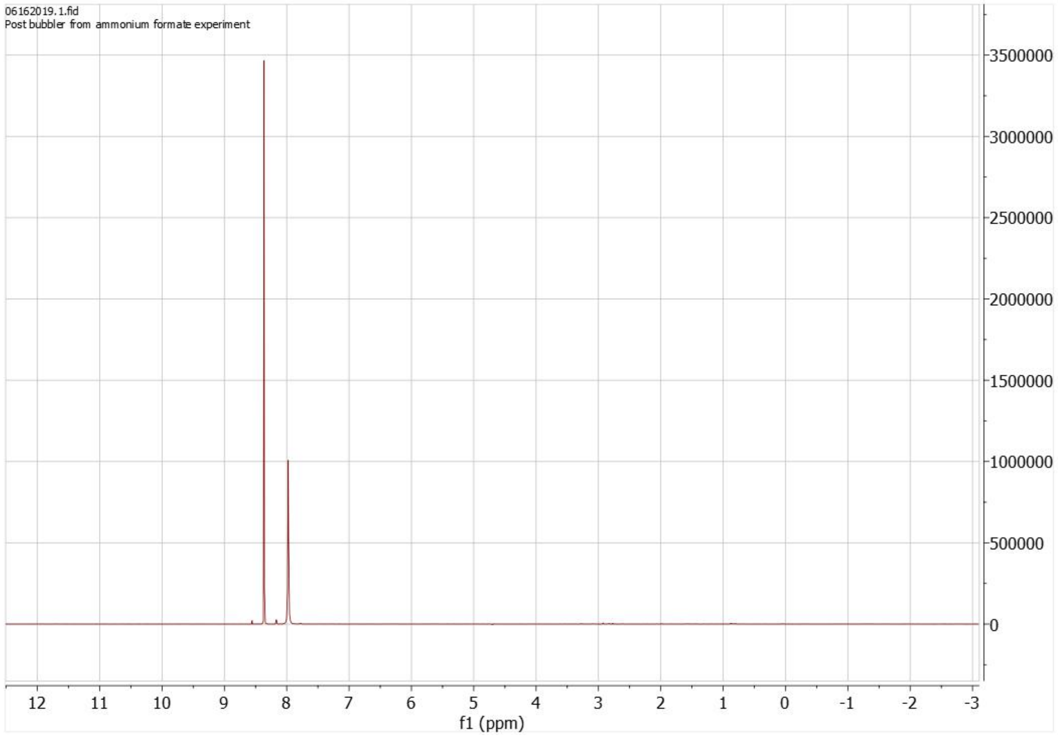
Average FE = 81±8%
(No evidence of $N_2$)

**Cathode**

| Current (mA) | FE toward $H_2$ |
|---|---|
| 1 | 138% |
| 3 | 100% |
| 5 | 96% |

Average FE = 110±10%

Evidence of formic acid/formate in post-cell trap




Spectrophotometric evidence of Ammonia in post-cell trap