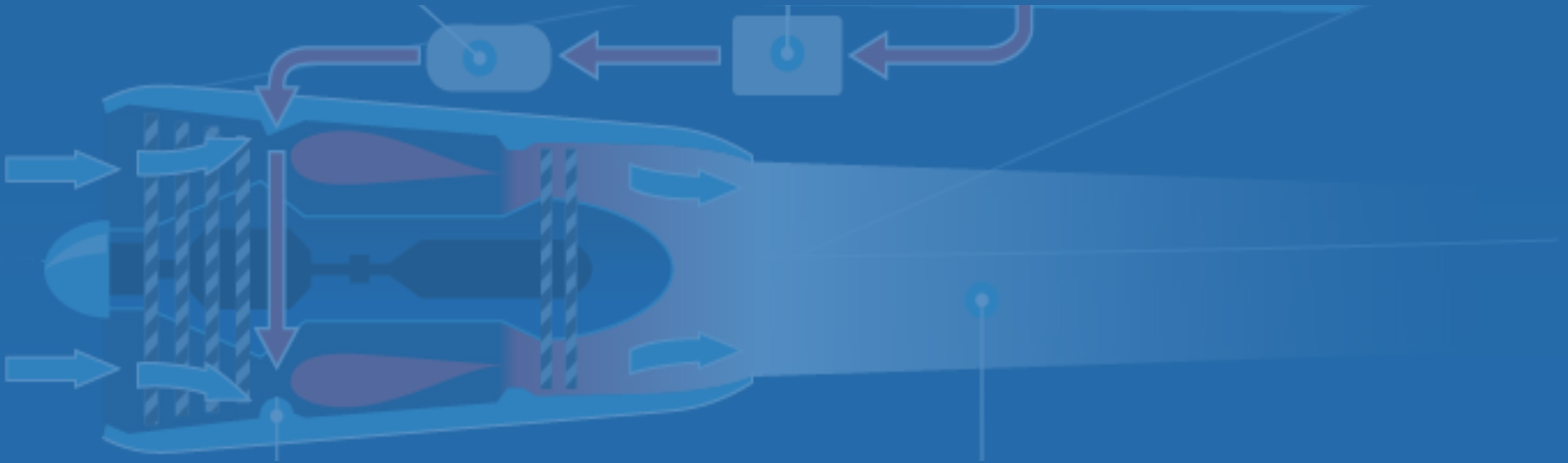
SUNBORNE SYSTEMS

… bringing <u>keystone</u> technologies to market for the global <u>zero-emissions</u> energy <u>infrastructure</u>



BILL DAVID
CSO | SUNBORNE SYSTEMS LTD.

INORGANIC CHEMISTRY LABORATORY | UNIVERSITY OF OXFORD
ISIS FACILITY | STFC RUTHERFORD APPLETON LABORATORY

GREEN NH_3 PRODUCTION

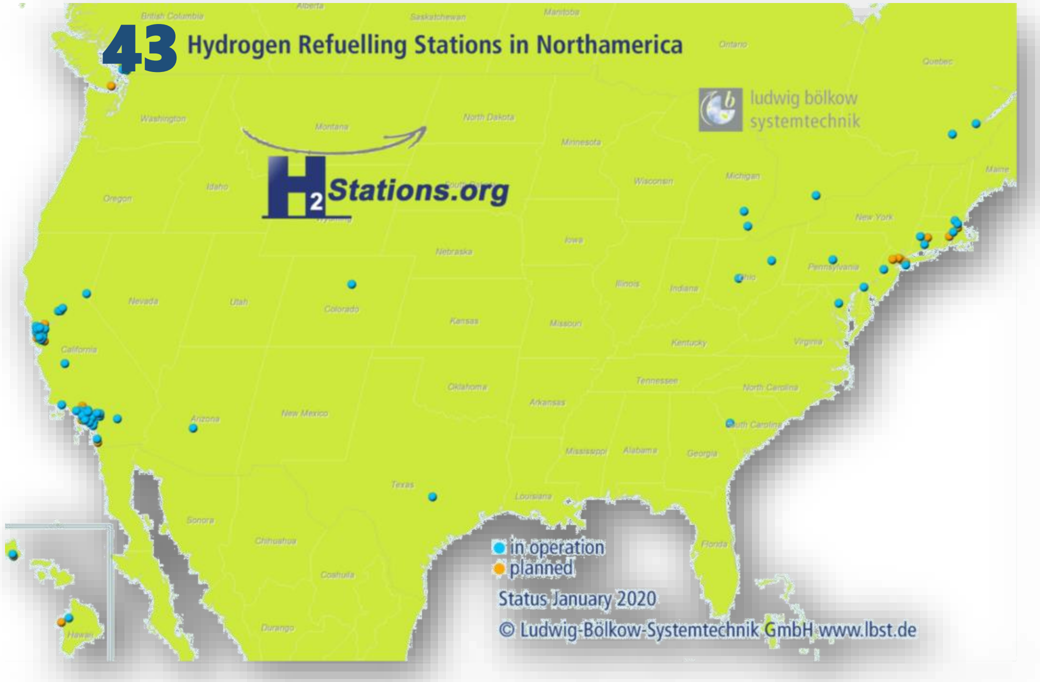
INTERNATIONALLY TRADED NH_3

GLOBAL NH_3 BUNKERING

DISTRIBUTED NH_3 STORAGE

FUEL STORAGE: USA STATUS

HYDROGEN (US distribution : 2020)



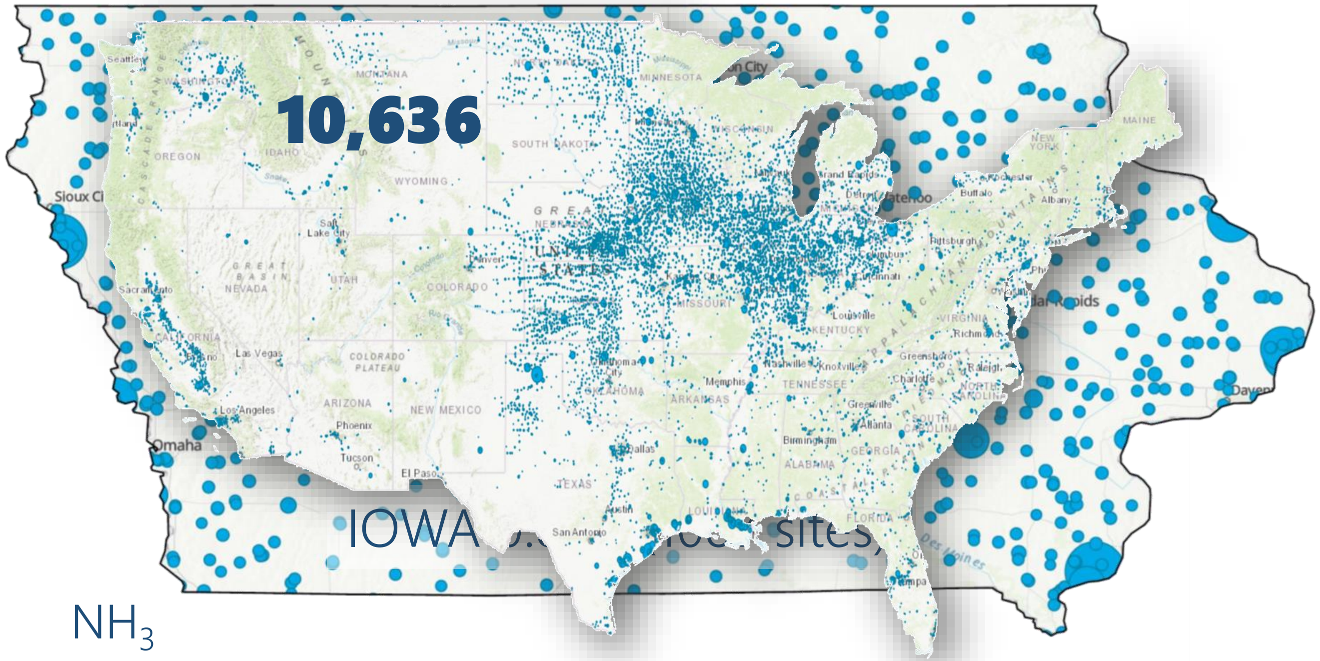
www.h2stations.org/wp-content/uploads/Northamerica-2020-k.jpg

43× 100kg/day × 250 days/year

→ 1075 tonnes H_2/year

→ 36GWh/year

AMMONIA (US distribution : 2012)



NH_3

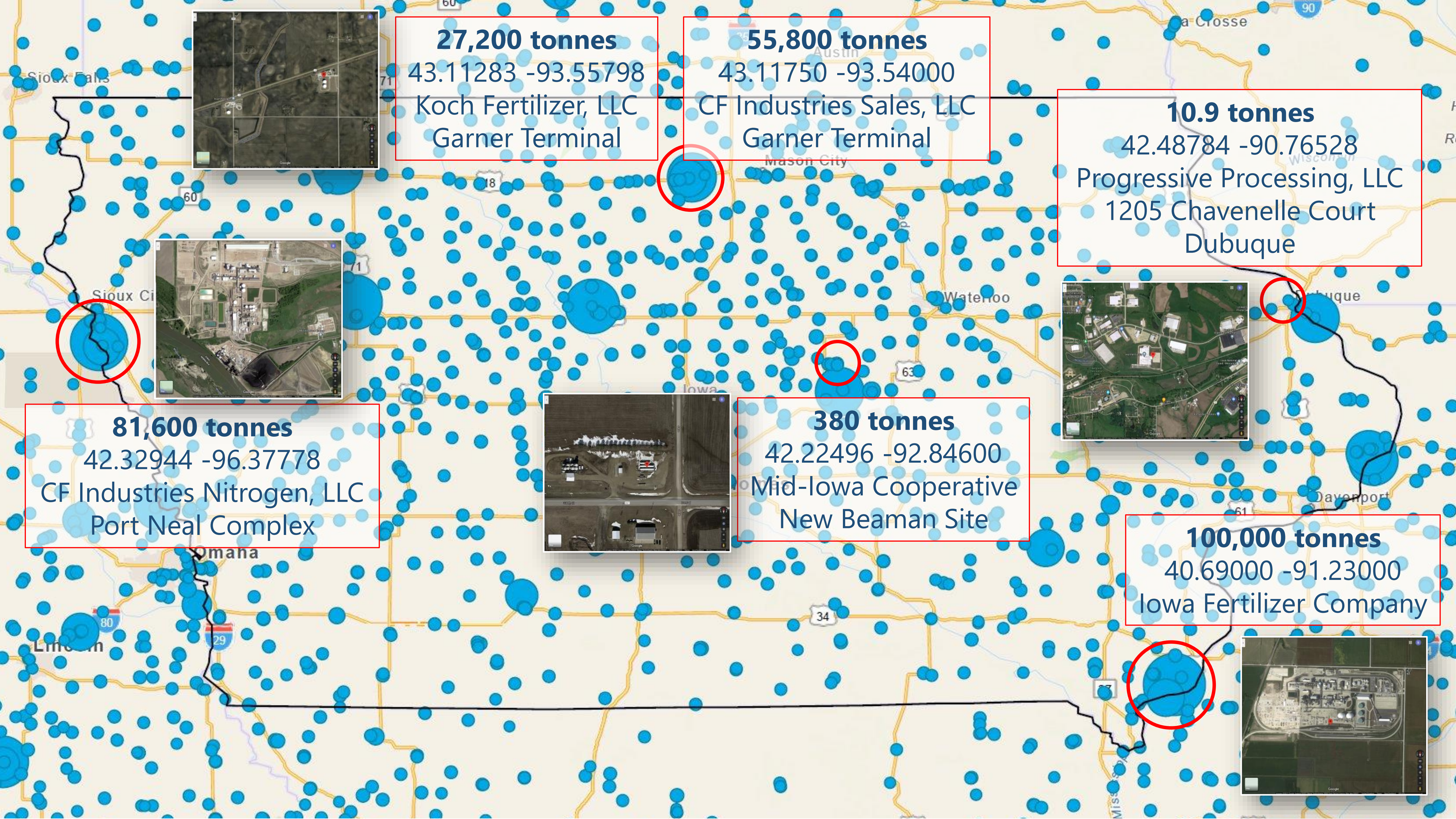
US: 10,636 sites (× 250)

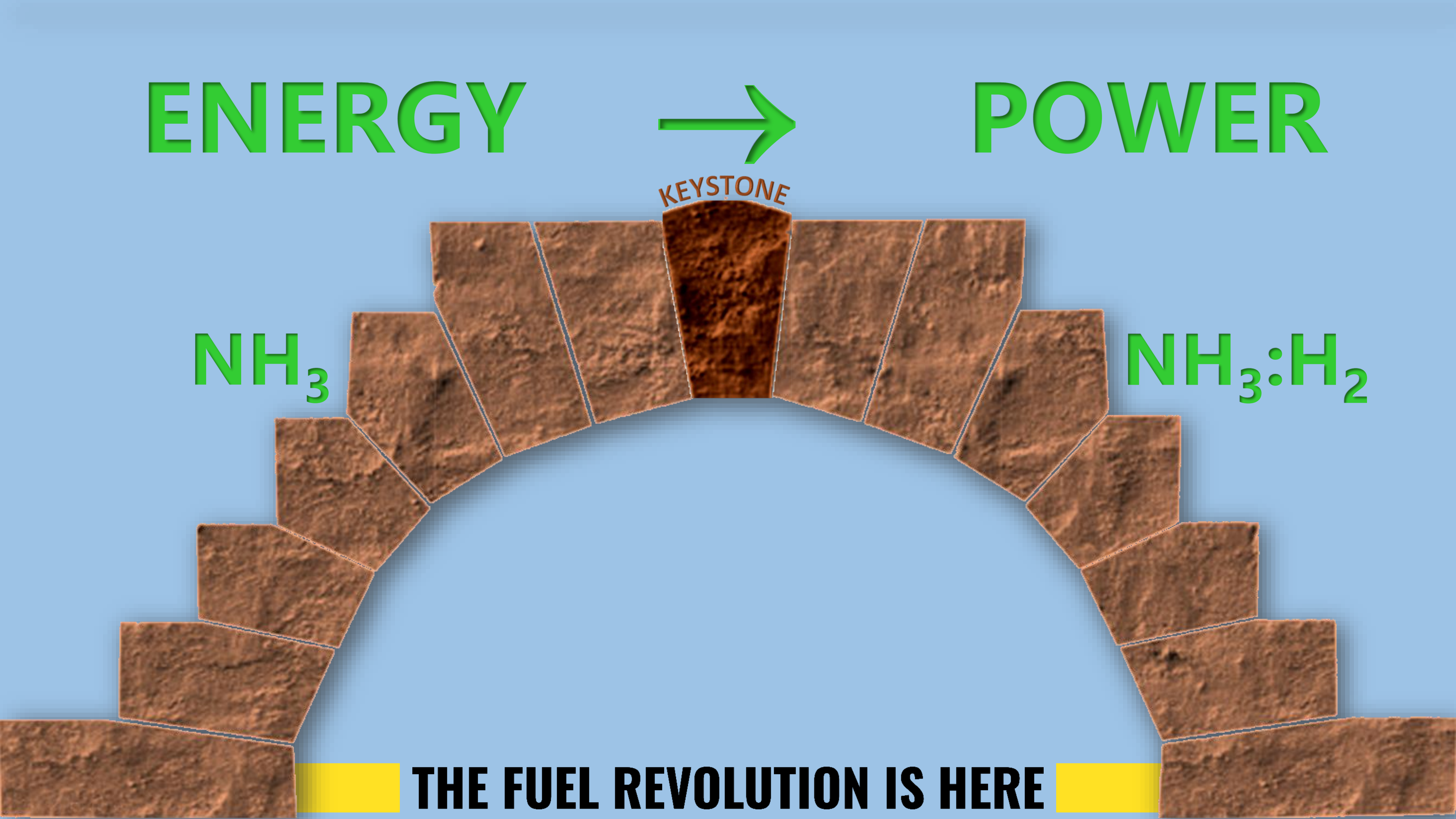
Capacity: 24.2Mt NH_3/year

Production: 22.2Mt NH_3/year

24.2Mt NH_3/year → **122TWh/year = 122,000GWh/year**

×3400 (146000)

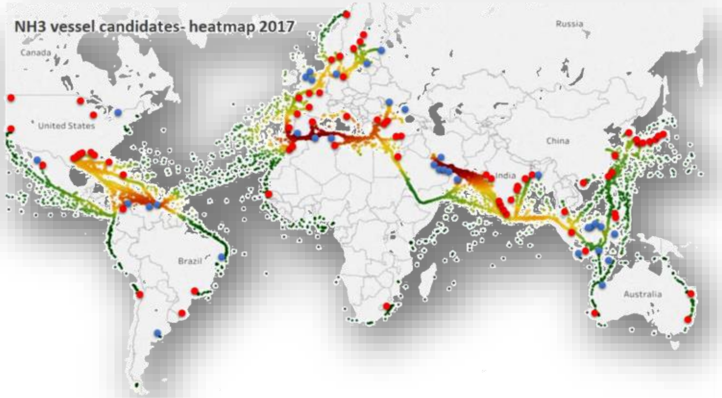

27,200 tonnes
43.11283 -93.55798
Koch Fertilizer, LLC
Garner Terminal
55,800 tonnes
43.11750 -93.54000
CF Industries Sales, LLC
Garner Terminal
10.9 tonnes
42.48784 -90.76528
Progressive Processing, LLC
1205 Chavenelle Court
Dubuque
81,600 tonnes
42.32944 -96.37778
CF Industries Nitrogen, LLC
Port Neal Complex
380 tonnes
42.22496 -92.84600
Mid-Iowa Cooperative
New Beaman Site
100,000 tonnes
40.69000 -91.23000
Iowa Fertilizer Company


ENERGY → POWER
KEYSTONE
NH_3
$NH_3:H_2$
THE FUEL REVOLUTION IS HERE

First ammonia engines for commercial use are due out in 2024

New test engine debuts on Copenhagen's roads during lockdown

17 June 2020 9:35 GMT UPDATED 17 June 2020 9:35 GMT



99.9999% conversion

$$NH_3 \rightarrow (<ppm)\ H_2$$

180,000,000 tonnes NH_3/year
~ 30,000,000 tonnes H_2/year
~250,000,000 cars
(× 4200)

AMMONIA | HYDROGEN

AMMONIA

<5%

SOFC

MARITIME

0 – 30%

ICE

~30%

AVIATION

retrofitted technologies
existing infrastructures
lowest disruption routes
lowest costs
'seamless' transition
de-demonising ICEs : addressing NOx

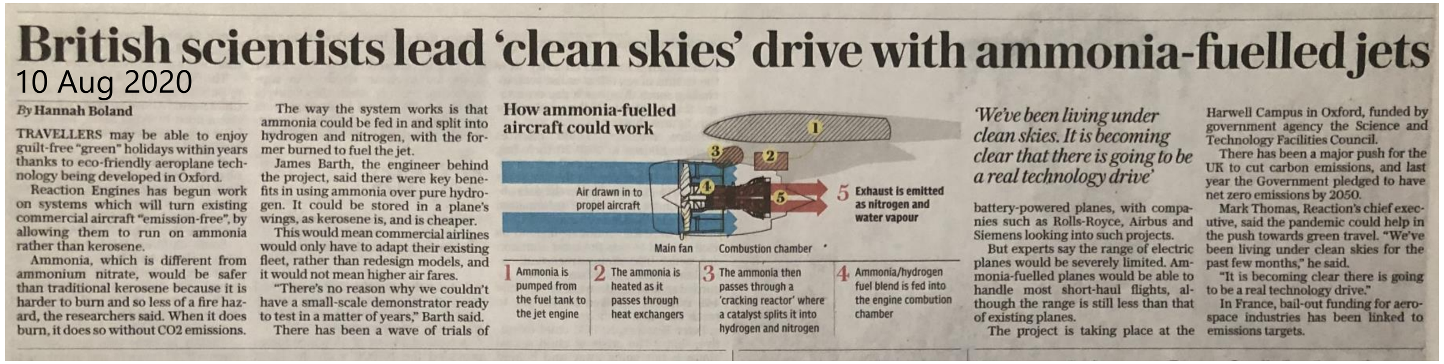
>90%

AFC

PEM

HYDROGEN

0% → CONVERSION → 100%



British scientists lead 'clean skies' drive with ammonia-fuelled jets

10 Aug 2020

By **Hannah Boland**

TRAVELLERS may be able to enjoy guilt-free "green" holidays within years thanks to eco-friendly aeroplane technology being developed in Oxford.

Reaction Engines has begun work on systems which will turn existing commercial aircraft "emission-free", by allowing them to run on ammonia rather than kerosene.

Ammonia, which is different from ammonium nitrate, would be safer than traditional kerosene because it is harder to burn and so less of a fire hazard, the researchers said. When it does burn, it does so without CO2 emissions.

The way the system works is that ammonia could be fed in and split into hydrogen and nitrogen, with the former burned to fuel the jet.

James Barth, the engineer behind the project, said there were key benefits in using ammonia over pure hydrogen. It could be stored in a plane's wings, as kerosene is, and is cheaper.

This would mean commercial airlines would only have to adapt their existing fleet, rather than redesign models, and it would not mean higher air fares.

"There's no reason why we couldn't have a small-scale demonstrator ready to test in a matter of years," Barth said.

There has been a wave of trials of battery-powered planes, with companies such as Rolls-Royce, Airbus and Siemens looking into such projects.

But experts say the range of electric planes would be severely limited. Ammonia-fuelled planes would be able to handle most short-haul flights, although the range is still less than that of existing planes.

The project is taking place at the Harwell Campus in Oxford, funded by government agency the Science and Technology Facilities Council.

There has been a major push for the UK to cut carbon emissions, and last year the Government pledged to have net zero emissions by 2050.

Mark Thomas, Reaction's chief executive, said the pandemic could help in the push towards green travel. "We've been living under clean skies for the past few months," he said.

"It is becoming clear there is going to be a real technology drive."

In France, bail-out funding for aerospace industries has been linked to emissions targets.

'We've been living under clean skies. It is becoming clear that there is going to be a real technology drive'

How ammonia-fuelled aircraft could work

Air drawn in to propel aircraft

Main fan

Combustion chamber

5 Exhaust is emitted as nitrogen and water vapour

1 Ammonia is pumped from the fuel tank to the jet engine

2 The ammonia is heated as it passes through heat exchangers

3 The ammonia then passes through a 'cracking reactor' where a catalyst splits it into hydrogen and nitrogen

4 Ammonia/hydrogen fuel blend is fed into the engine combution chamber

AFC Energy

100kg/day × 150 days × 500 stations
= 7,500 tonnes/year | 60,000 cars

SUNBORNE SYSTEMS

WELCOME TO THE AMMONIA AGE

sunbornesystems.com

THE FUEL REVOLUTION IS HERE

A NEW COMPANY WITH YEARS OF EXPERIENCE

THREE UNIQUE CAPABILITIES:

- Thermal management
- Catalyst chemistry
- System design and optimisation

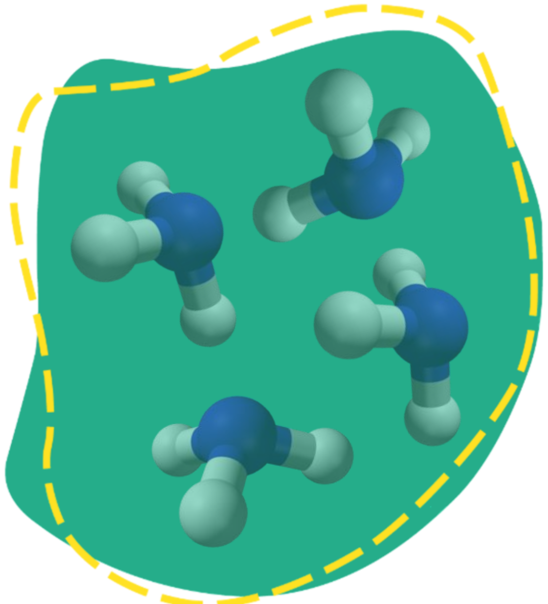
FROM TWO TRAILBLAZING ORGANISATIONS:

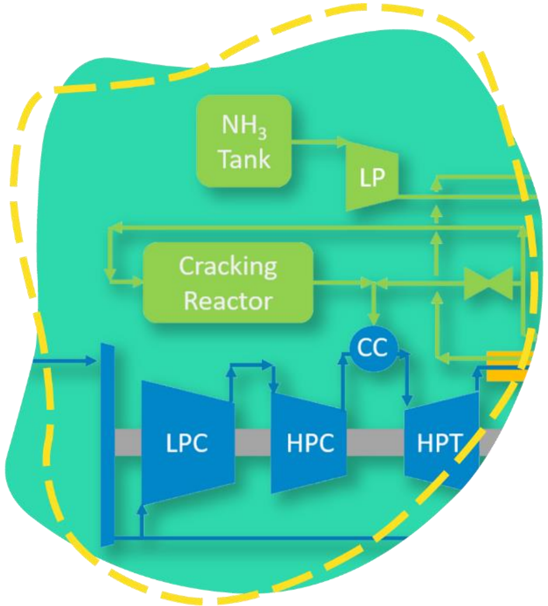
- Reaction Engines
- UKRI Science and Technology Facilities Council

RESULTING IN ONE PIONEERING NEW COMPANY

SUNBORNE SYSTEMS

THREE UNIQUE CAPABILITIES





THERMAL MANAGEMENT

Our unbeatable heat exchanger technology lets us build compact, lightweight reactors that efficiently move heat into the reaction zone to maintain catalytic activity at the desired level.

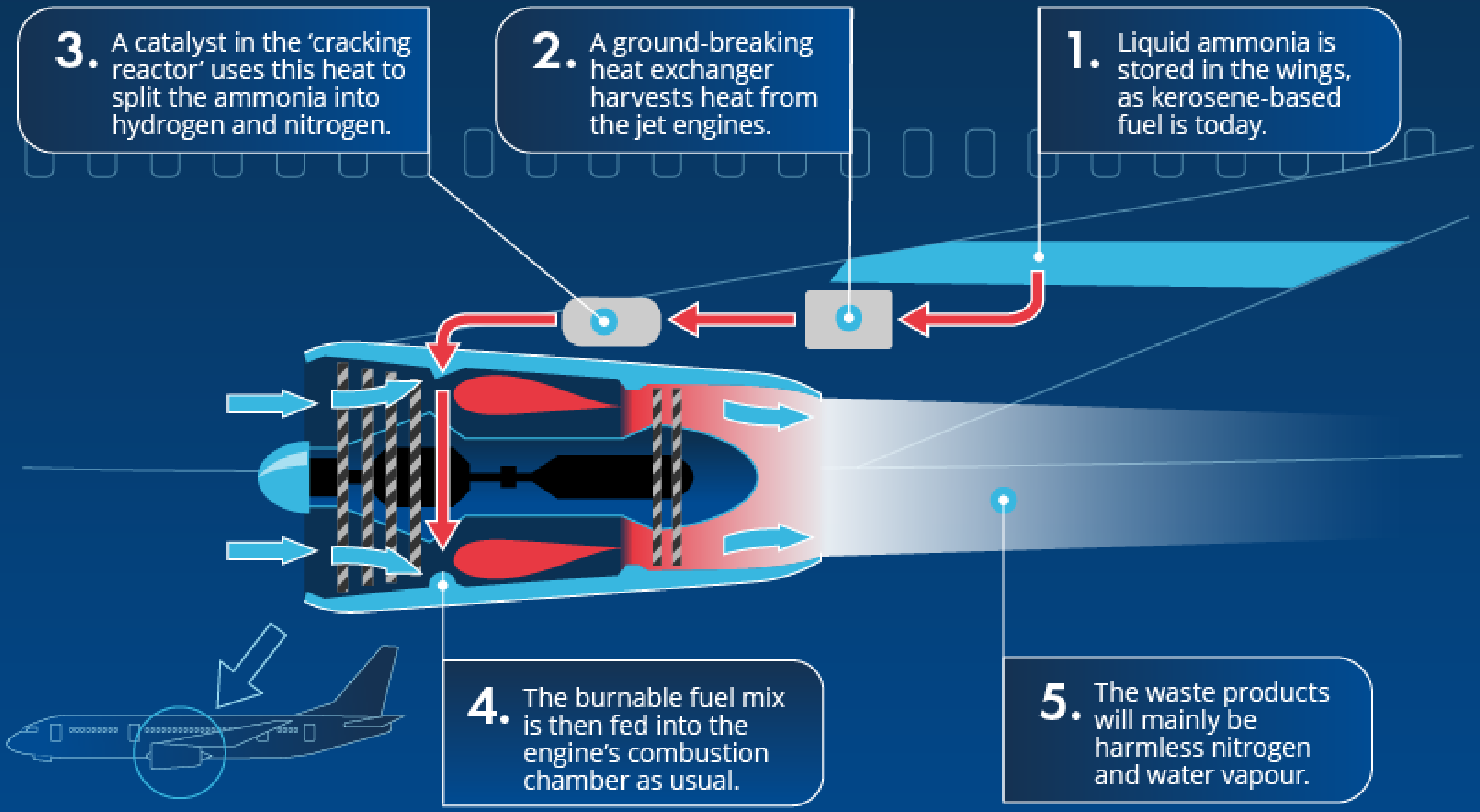
CATALYST CHEMISTRY

Our unique catalyst chemistry allows more efficient cracking of ammonia, at lower temperatures and higher pressures than other catalysts.

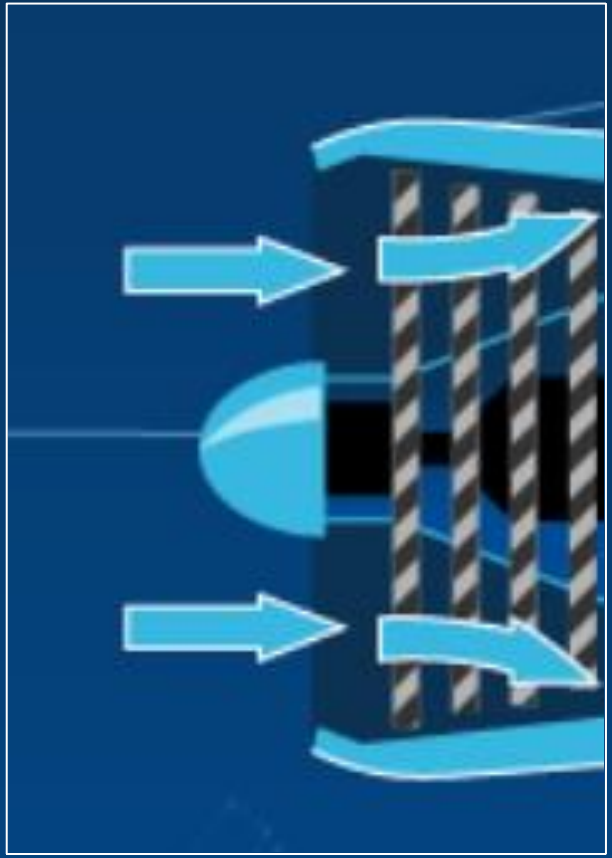
SYSTEM DESIGN AND OPTIMISATION

We can assist with design and optimisation of entire systems built around our unique technology.

How ammonia could fuel future jet engines



AIR INTAKE



$100\ O_2 \equiv 3200g$

JET FUEL

$C_{13.5}H_{29}$

$$C_{13.5}H_{29} + 41.5\,O_2 \rightarrow 14.5\,H_2O + 13.5\,CO_2$$

$$100\ O_2 \equiv 2.41\ C_{13.5}H_{29} \equiv 921g\ C_{13.5}H_{29}$$

weight: ammonia/ jet fuel

$2267g / 921g = 2.46$

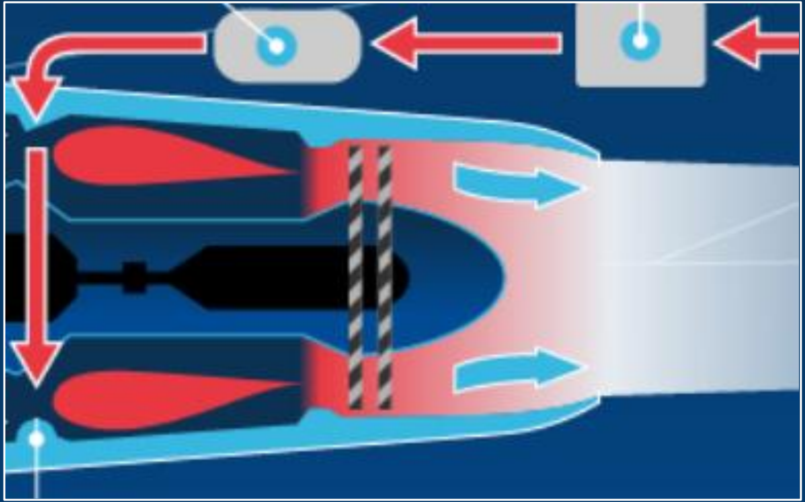
$$100\ O_2 \equiv 133\ NH_3 \equiv 2267g\ NH_3$$

$$4\,NH_3 + 3\,O_2 \rightarrow 6\,H_2O + 2\,N_2$$

AMMONIA

NH_3

PRODUCING POWER



JET FUEL:	11.9 MWh/t	9.52 MWh/m^3
AMMONIA:	5.1 MWh/t	3.57 MWh/m^3
HYDROGEN:	33.3 MWh/t	

70:30 uncracked | cracked NH_3

70% × 3.57   30% ≡ 210kg $NH_3 \rightarrow$ 37kg H_2

2.50 MWh/m^3 + 1.23 MWh/m^3

BURNING SPEED

JET FUEL:	**92 cm/s**
AMMONIA:	8.23 cm/s
HYDROGEN:	296 cm/s
70% NH_3 | 30% H_2:	**139 cm/s**
	89 cm/s

ratio of energy/m^3 between partially cracked NH_3 and jet fuel

3.73 / 9.52 = 0.392

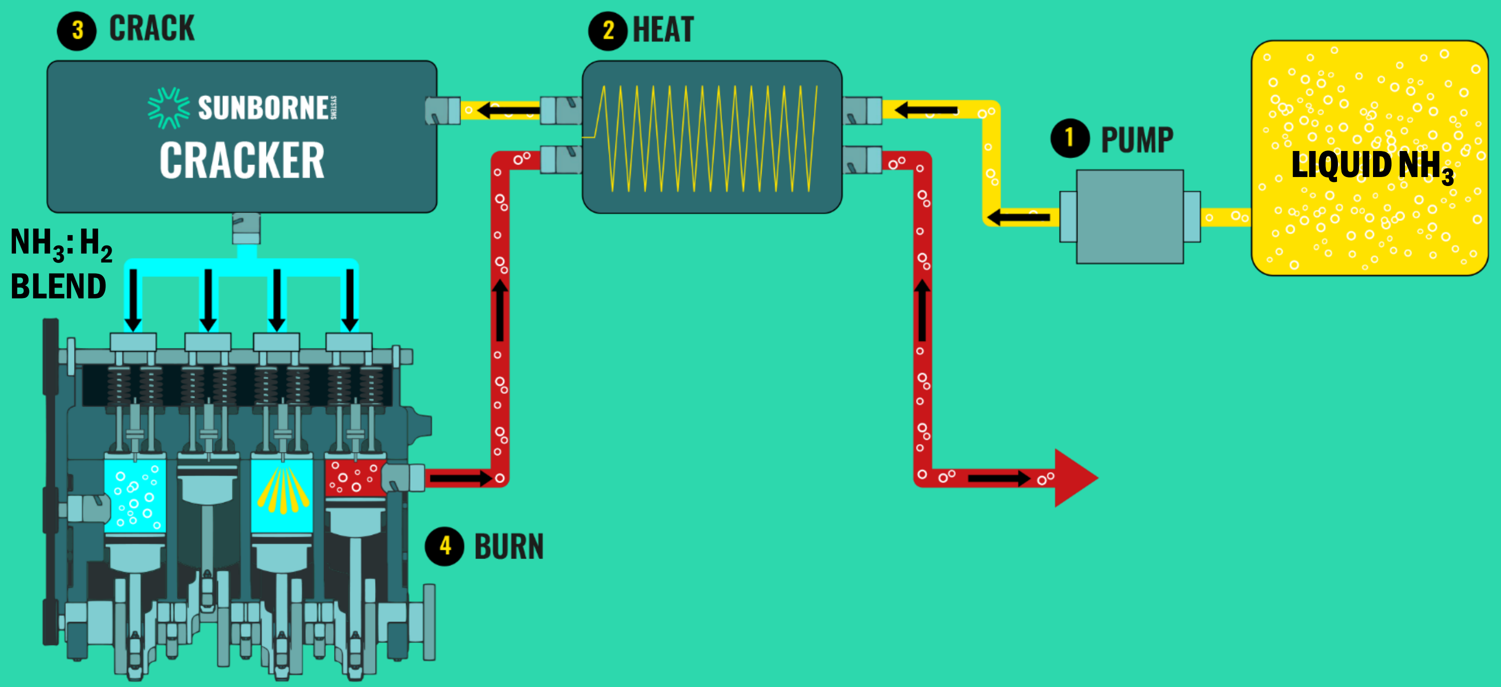
ammonia is used up more quickly than jet fuel

2267g / 921g = 2.46

ratio of engine power between partially cracked NH_3 and jet fuel

0.392×2.46 = 96%

OUR TECHNOLOGY SOLUTION

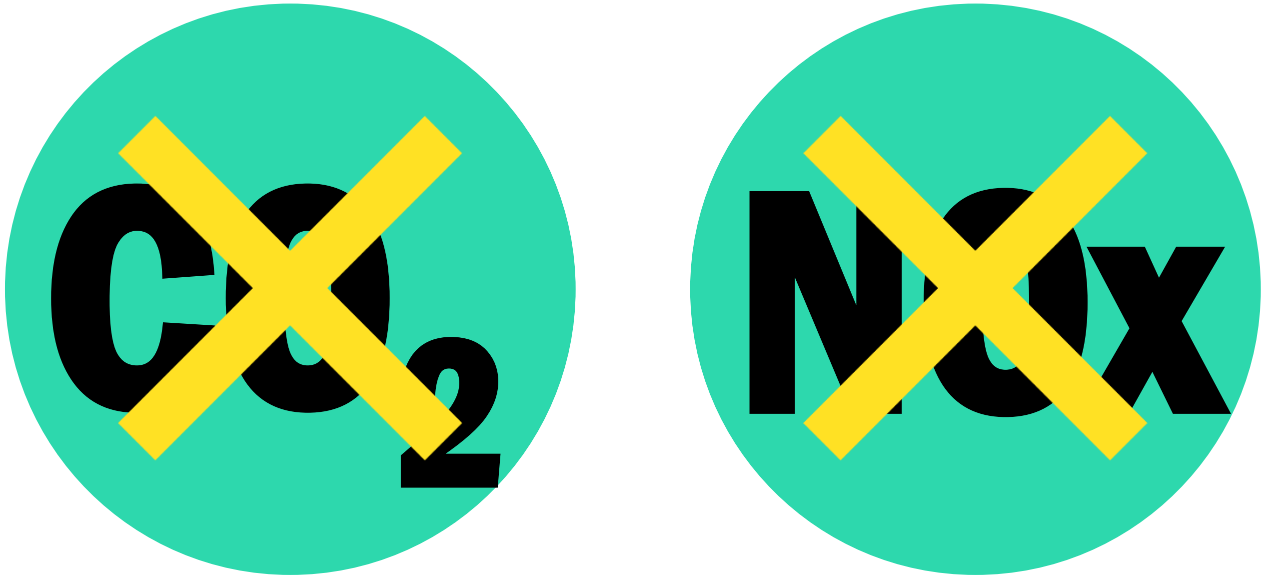


INTEGRATED REACTOR SYSTEMS

- Allows existing engine architectures to convert to ammonia fuel
- Inline cracking takes otherwise wasted heat and puts it back into the fuel
- Cracking into an ammonia/ hydrogen blend solves combustion stability issues
- Overall system efficiency improves as a result

REASON 1: NO HARMFUL EMISSIONS

With zero CO_2 and NOx emissions, our reactors enable true-zero impact system solutions.



REASON 2: NO PILOT FUELS NEEDED

Our technology turns ammonia into a self-igniting, stable-burning fuel blend, which makes pilot fuels a thing of the past.

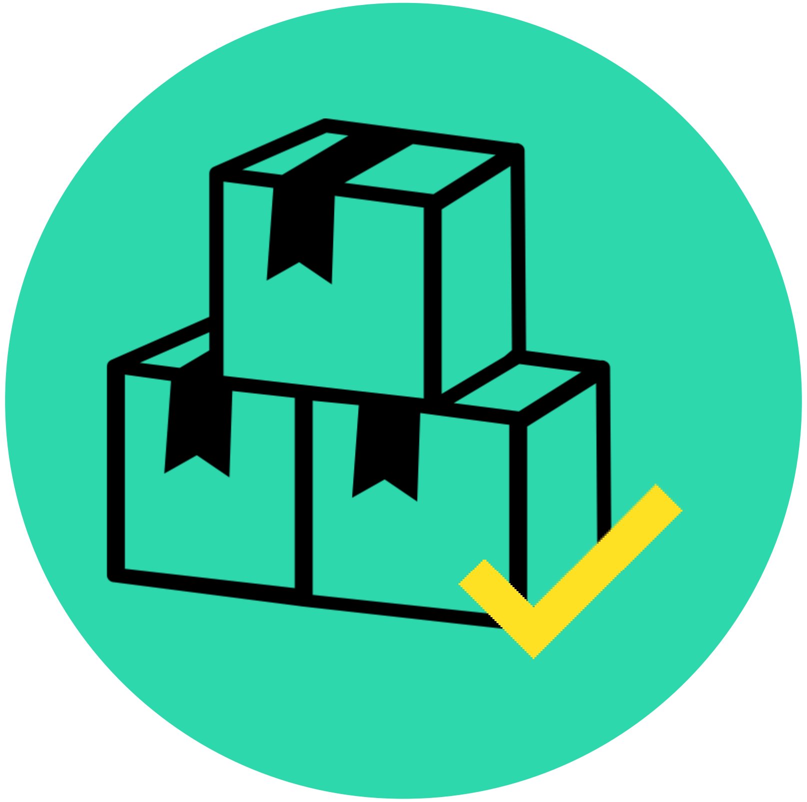
REASON 3: 10× SMALLER AND LIGHTER

Significantly smaller and lighter than other reactors, our systems fit where few can follow.

REASON 4: NO RISK TO AVAILABILITY

We are developing catalyst materials that crack ammonia 50° –100° cooler than competing offerings.

Better still, our catalysts eliminate expensive rare metals, de-risking our supply chain.



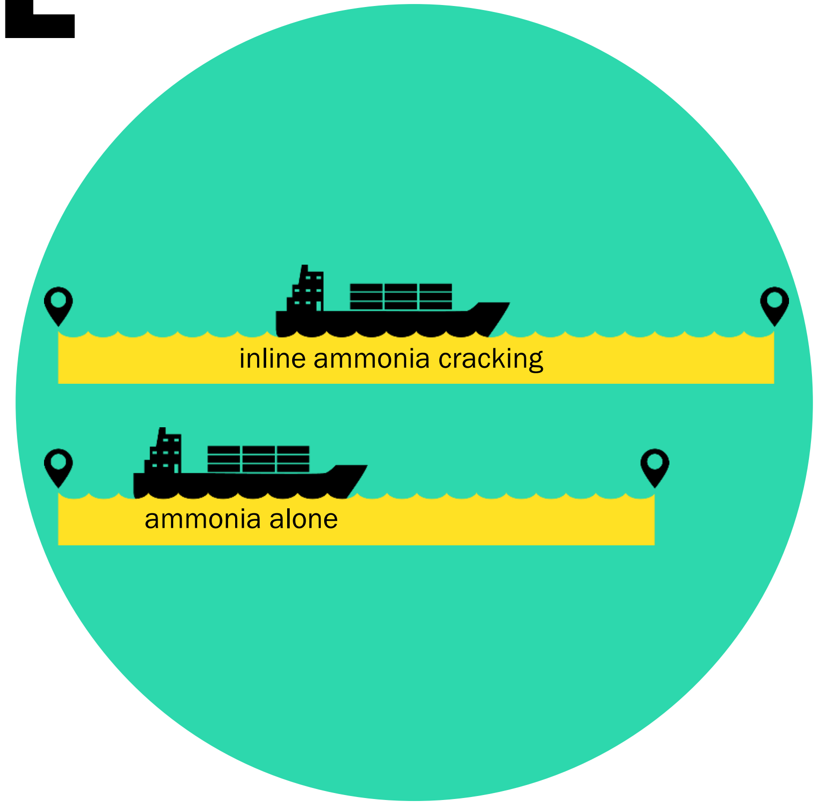
REASON 5: NO STRANDED ASSETS

Our technology is retrofittable in most systems, extending their life and saving cost.

REASON 6: 20% MORE RANGE THAN 2-FUEL SYSTEMS

A 30 MW container ship engine will burn ~3500 Tonnes less ammonia each year using Sunborne's proprietary technology, a fuel cost saving of at least $1 million*.

Our efficiency offering doesn't just save time and fuel cost; it also means fewer stops along the way.

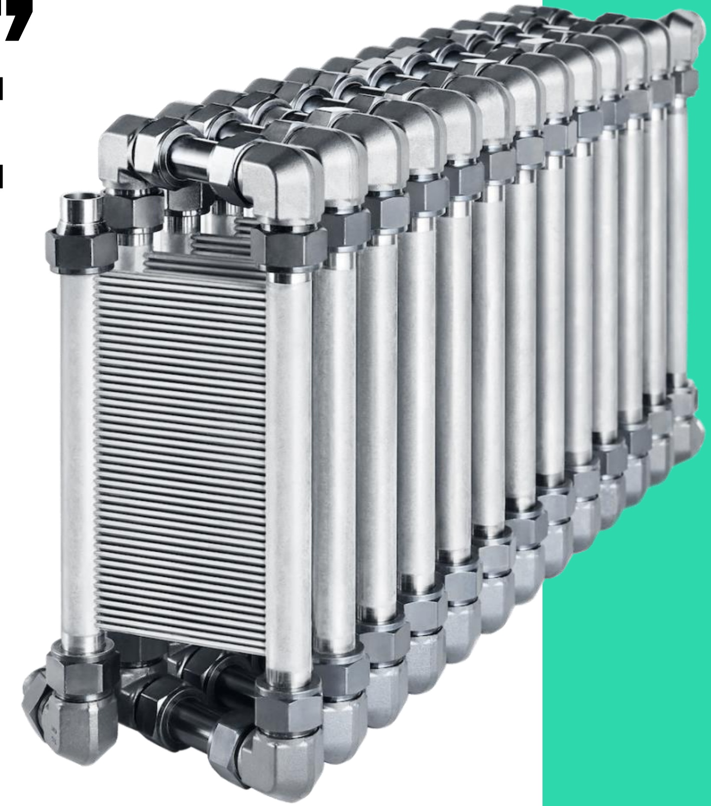


*Assuming a green ammonia cost of $320/T, based on targeted $2/kg green hydrogen cost in 2030

~~IM~~POSSIBLE, ~~IM~~PRACTICAL, ~~UN~~AVAILABLE

Truly novel ammonia-cracking technology.

A solution to the world’s hardest decarbonisation problems.

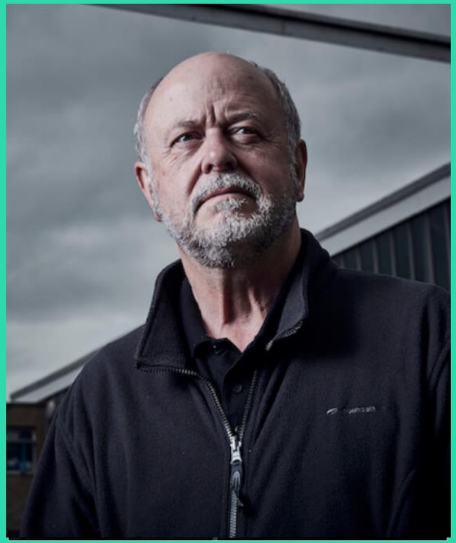


- EFFICIENT
- RETROFITTABLE
- COST-EFFECTIVE

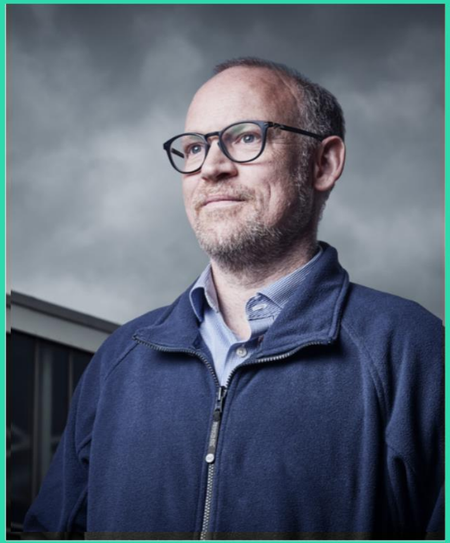
SUNBORNE SYSTEMS

THANK YOU

DR JAMES BARTH
CEO



PROF BILL DAVID
CSO



DR HAMISH NICHOL
CPDO

DR TOM WOOD
HEAD OF CHEMISTRY