

May 2022

Technological Options for Green Ammonia Production

KBR Sustainable Technology Solutions

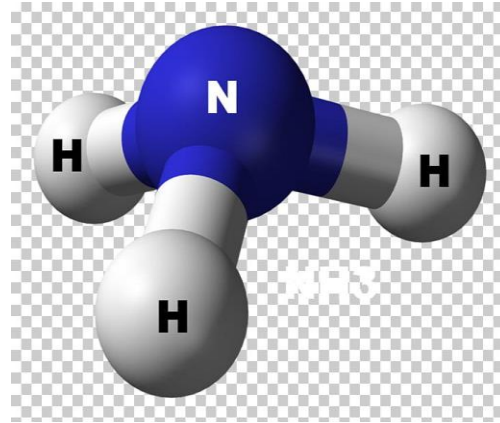
Harsh Kumar / Akhil Nahar



Delivering Solutions, Changing the World.SM

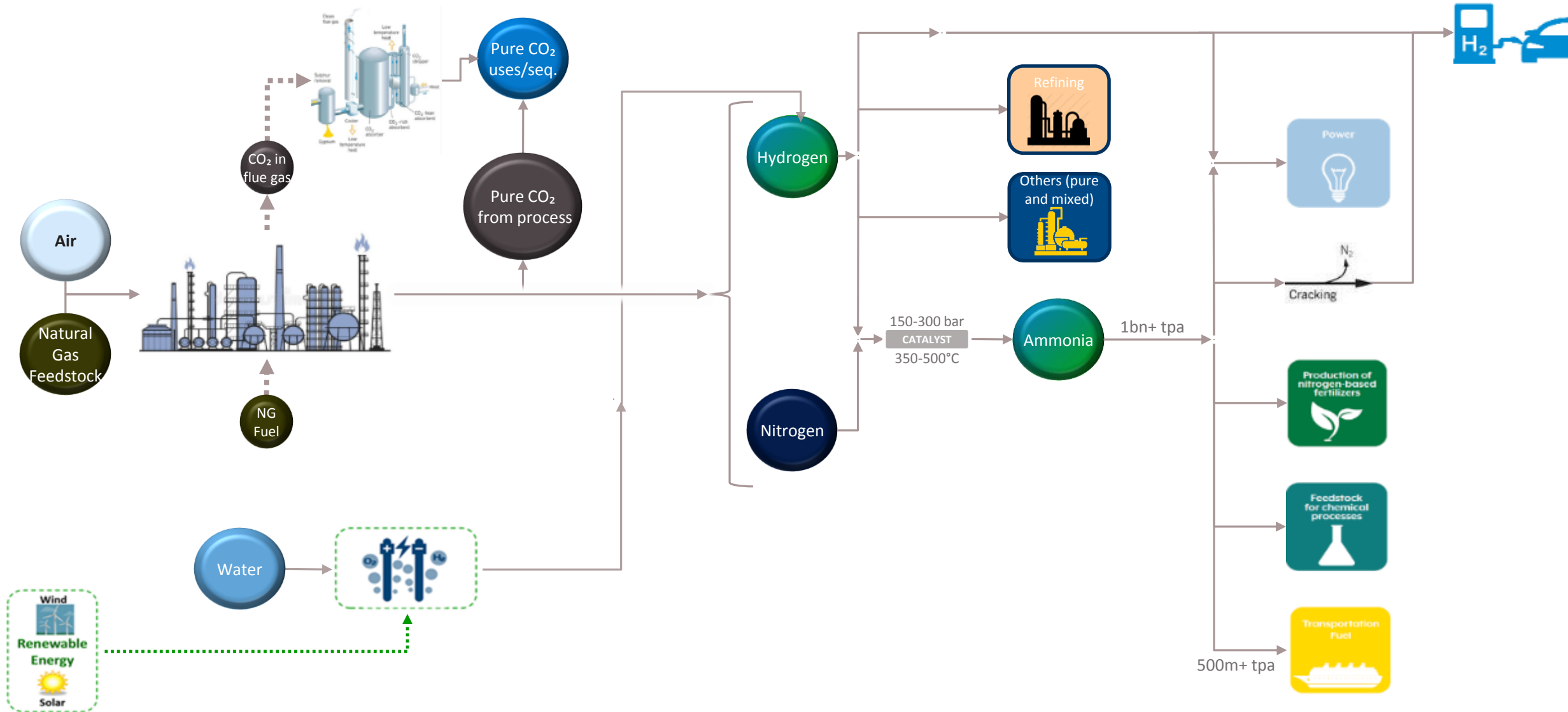


- Ammonia though does not emit any during combustion, but emission of CO₂ is ~1.6 T – 4 T/T of NH₃ if produced in a conventional way



- Increased interest in Ammonia as a Green Fuel
- Ammonia is carbon free Hydrogen carrier and can be produced from renewable sources
- Unlike traditional fuel Ammonia won't emit any carbon oxides on combustion making it fit candidate for Green fuel
- Energy Density of Ammonia is 12.5 MJ/L (HHV basis) which is half of the typical hydrocarbon fuel

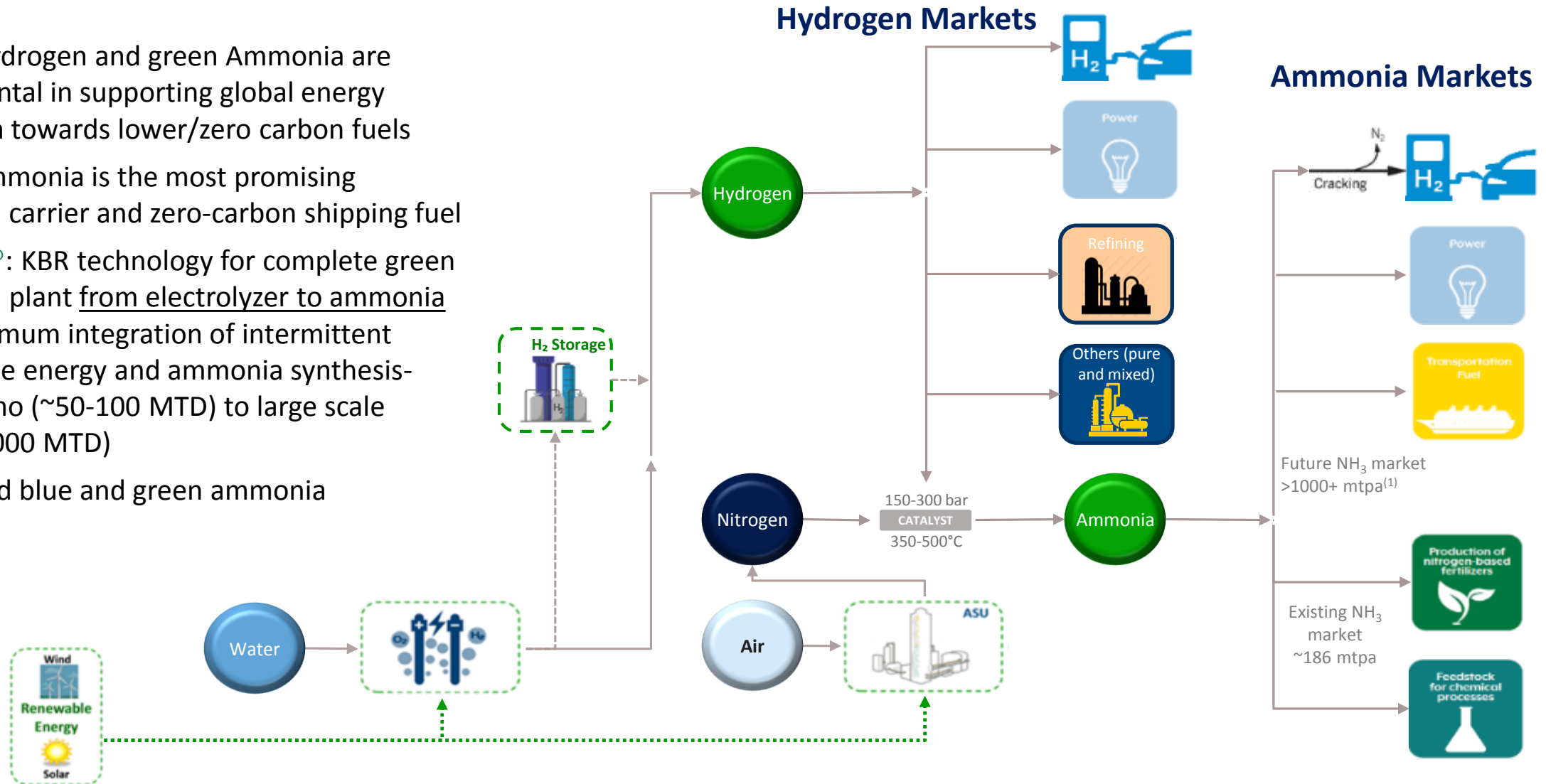
Roadmap Toward Decarbonizing Ammonia Production: Blue & Green



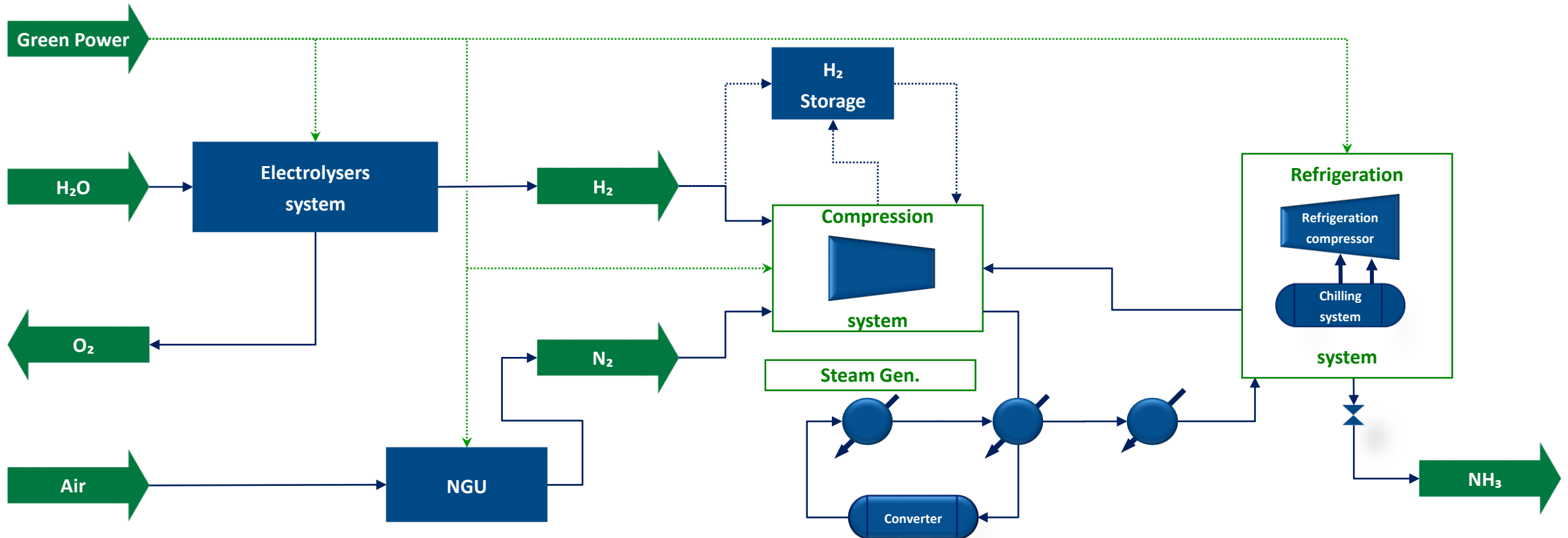
Green H₂ & NH₃: Zero Carbon Energy & Fuel



- Green Hydrogen and green Ammonia are instrumental in supporting global energy transition towards lower/zero carbon fuels
- Green ammonia is the most promising hydrogen carrier and zero-carbon shipping fuel
- K-GreenN[®]**: KBR technology for complete green ammonia plant from electrolyzer to ammonia with optimum integration of intermittent renewable energy and ammonia synthesis—from demo (~50-100 MTD) to large scale (up to 6,000 MTD)
- Combined blue and green ammonia



K-GreenN[®] - Complete Solution From Renewable Energy to Green Ammonia



Design for:

- Minimum turndown capacity
- Flexibility in ramp-up/ramp-down
- Optimized storage of feedstock/product

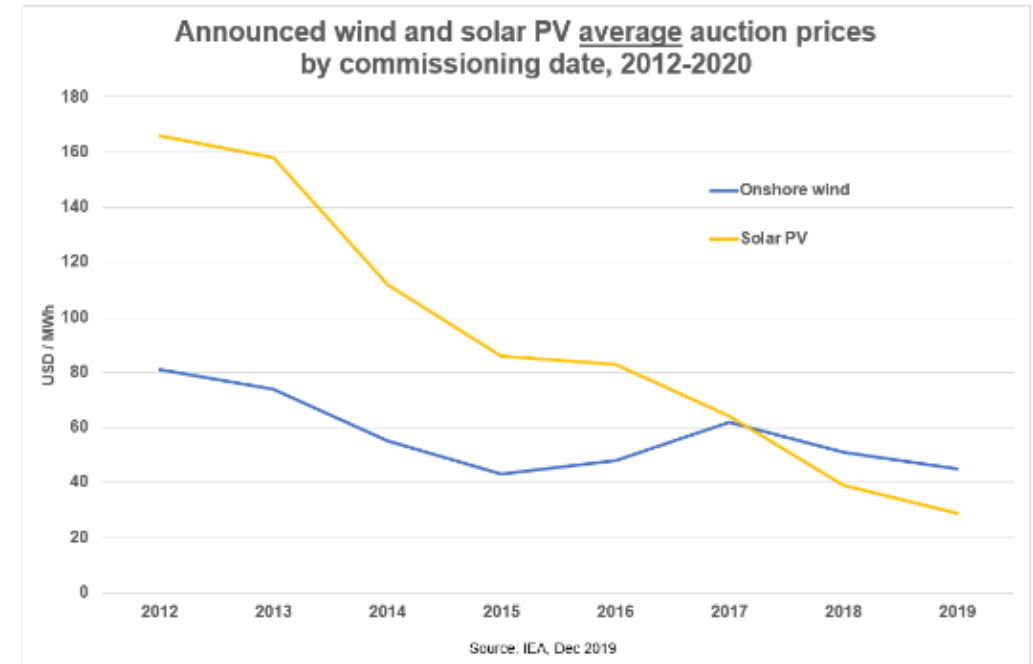
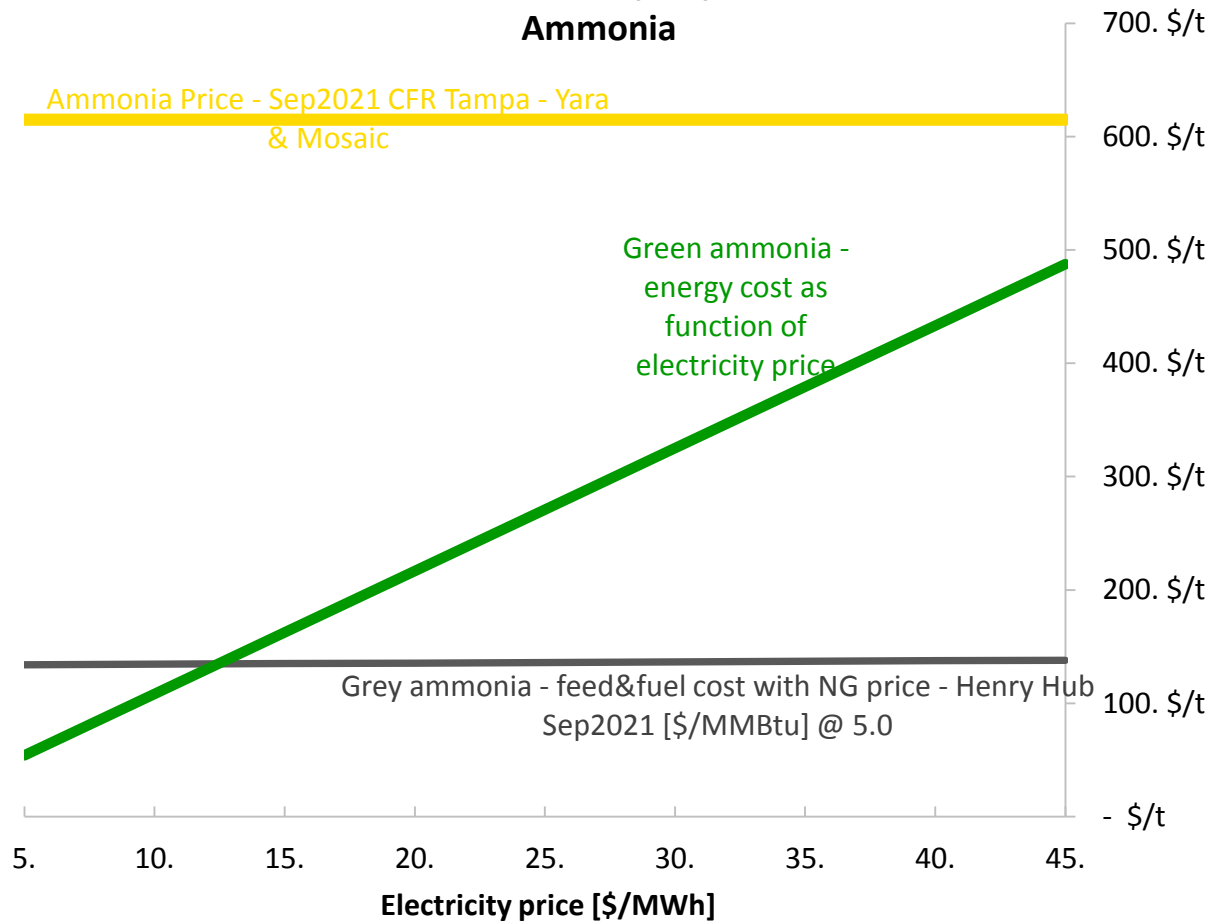
Various capacities:

- Demonstration units (4-200 MTPD)
- Small-size (200 - 600 MTPD)
- World-scale (600 - 6,000 MTPD)

Producing Green H₂ & NH₃ Today: Challenges & Opportunities



Cost of feedstock+fuel / electricity to produce 1 metric ton of Ammonia

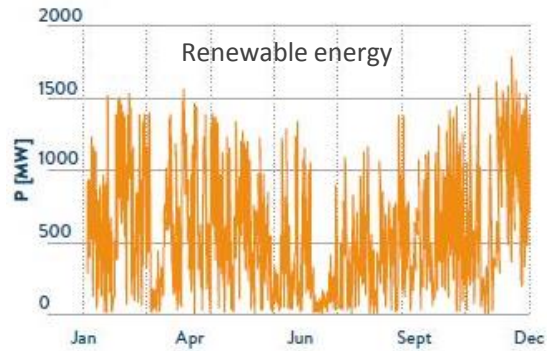


Portugal's second PV auction draws world record low bid of \$0.0132/kWh

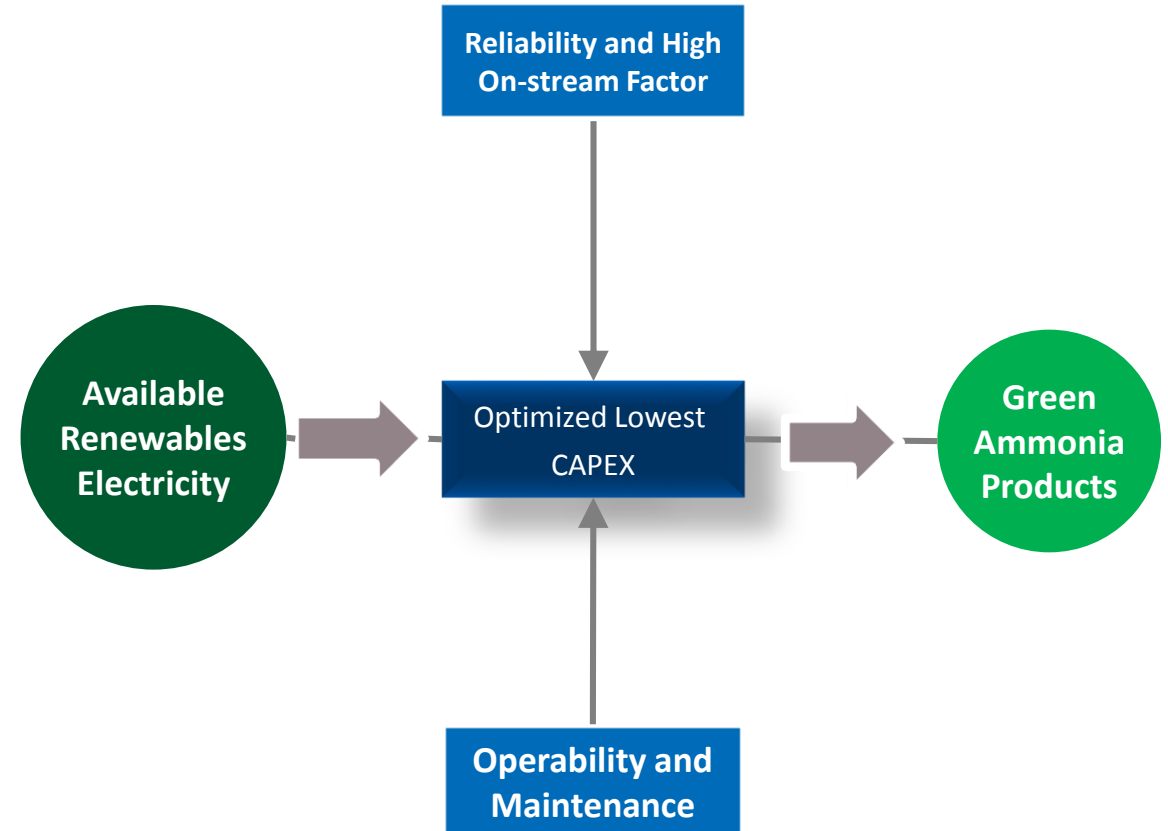
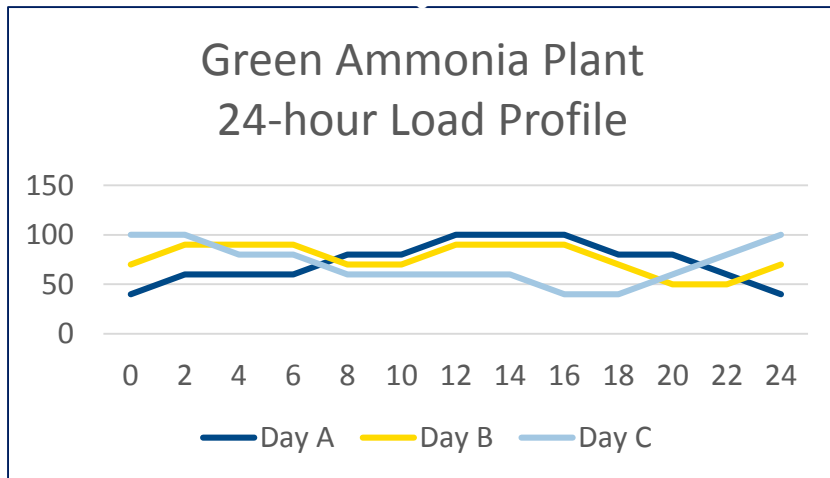
According to financial newspaper *Expresso*, the lowest bid in the exercise was €0.0112/kWh, slightly lower than the \$0.0135/kWh submitted by French energy group EDF and China's JinkoPower in a 2 GW tender held in Abu Dhabi, a price which was confirmed last month.

AUGUST 24, 2020

Power Variability- Biggest Concern for Green Ammonia



Make to Profile smooth for Operability and Reliability

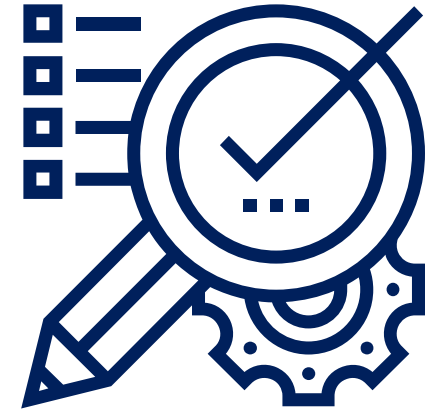


Turndown

- Low Turndown- maximum benefit, but how low we can go?
- KBR has unique operating experience of turndown operation @ 30%
- 10% turndown is possible!

Ramp Rate

- Ramp up/Ramp down: 50%-70% per hour
- Depending on the electricity profile, Storage(s) not a strong function of ramp down/ramp up

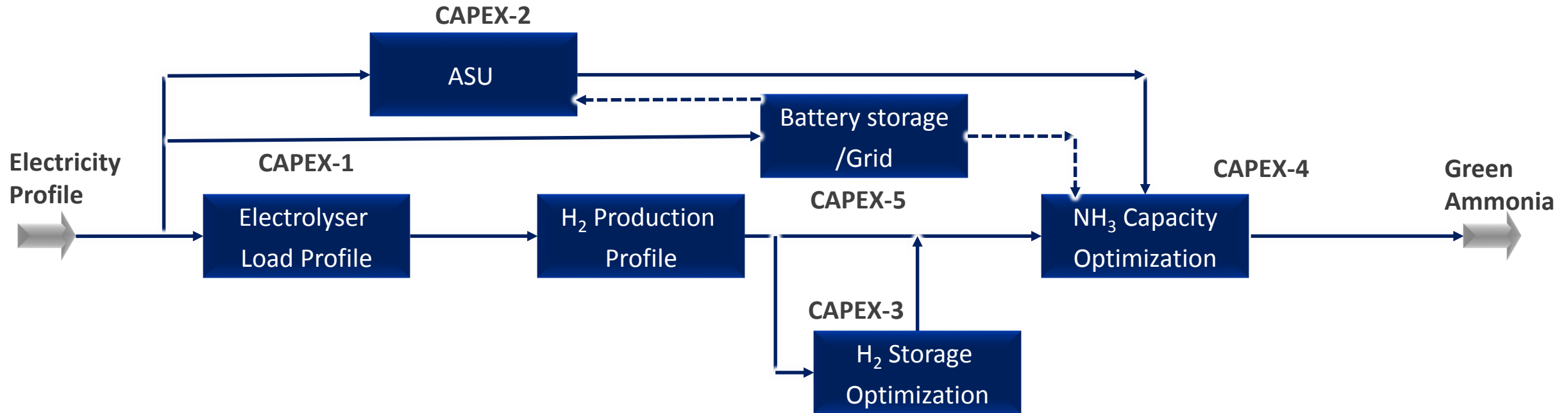


Hydrogen & Battery storage calculation- example



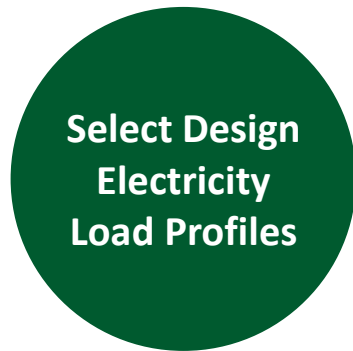
		Hydrogen Storage Volume (Tonnes)									
		Turn Down									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
R a m p	5%	85	85	85	85	85	85	87	91	98	107
	10%	64	64	65	67	70	75	81	88	97	107
	20%	38	43	49	55	62	69	78	87	97	107
	30%	29	36	43	51	59	68	77	87	97	107
	40%	25	32	41	49	58	67	77	87	97	107
	50%	22	31	39	48	57	67	77	87	97	107
	60%	21	29	38	47	57	67	77	87	97	107
	70%	19	28	37	47	57	67	77	87	97	107
	80%	18	27	37	47	57	67	77	87	97	107
	90%	17	27	37	47	57	67	77	87	97	107
100%	17	27	37	47	57	67	77	87	97	107	

		Battery storage volume (MWhr)									
		Turn Down									
		10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
R a m p	5%	363	363	363	363	363	363	364	369	380	400
	10%	339	339	340	342	346	351	356	364	379	400
	20%	307	314	322	329	337	345	352	361	379	400
	30%	296	306	316	325	334	343	351	361	379	400
	40%	291	301	313	323	333	341	351	361	379	400
	50%	287	299	311	321	331	341	351	361	379	400
	60%	286	298	310	320	331	341	351	361	379	400
	70%	284	297	308	320	331	341	351	361	379	400
	80%	283	295	308	320	331	341	351	361	379	400
	90%	281	295	308	320	331	341	351	361	379	400
100%	281	295	308	320	331	341	351	361	379	400	

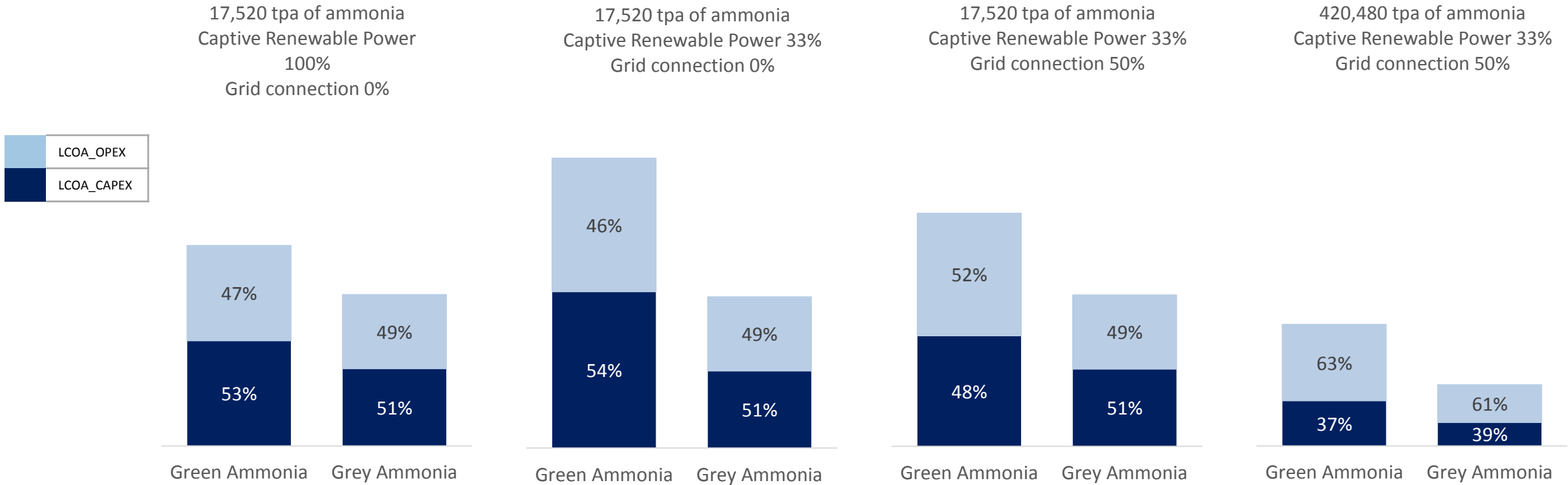


Examples:

- Average strongest/weakest wind day
- Winter/Summer day



Levelized Cost of Ammonia (LCOA)



Main Assumptions:

1. NG price - Henry Hub Sep2021 [\$/MMBtu] @ 5 \$/MMBTU
2. LCOE Captive Renewable Power @ 13.2 \$/MWh
3. PPA off-peak price @ 35 \$/MWh
4. Discount rate @ 10%



- The Answer is NO
- The unit is customized for that capacity
- Repeat order saves engineering cost and bulk order will provide cost advantage
- However, this is true for any capacity
- Implementation time is similar for smaller or bigger capacity. Difference may arrive if capacity difference is huge but not substantial
- Bigger capacity is better if installed at one location
- Specific consumption of feedstock does not drastically change with capacity

Advantages of small capacity units (higher number of plant)

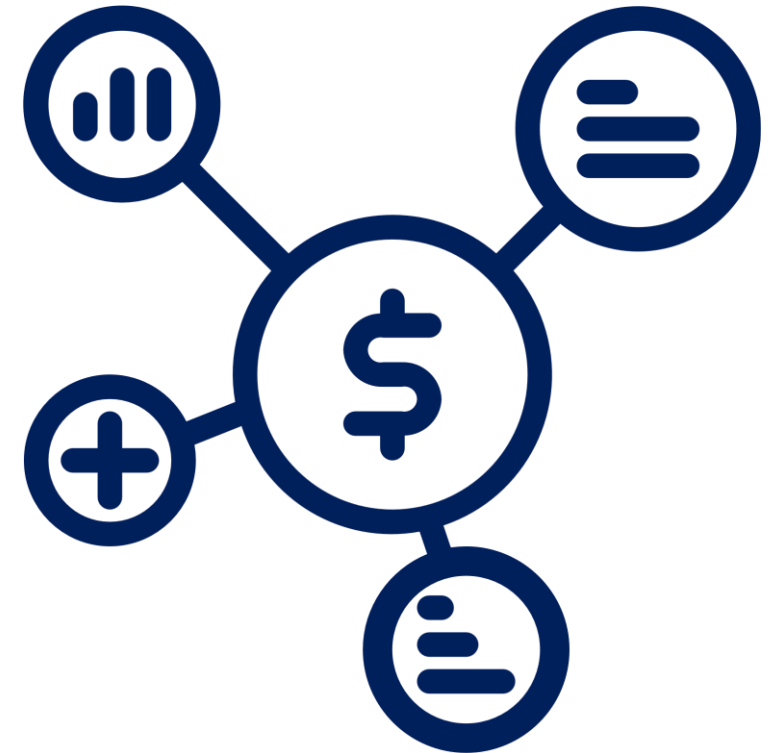
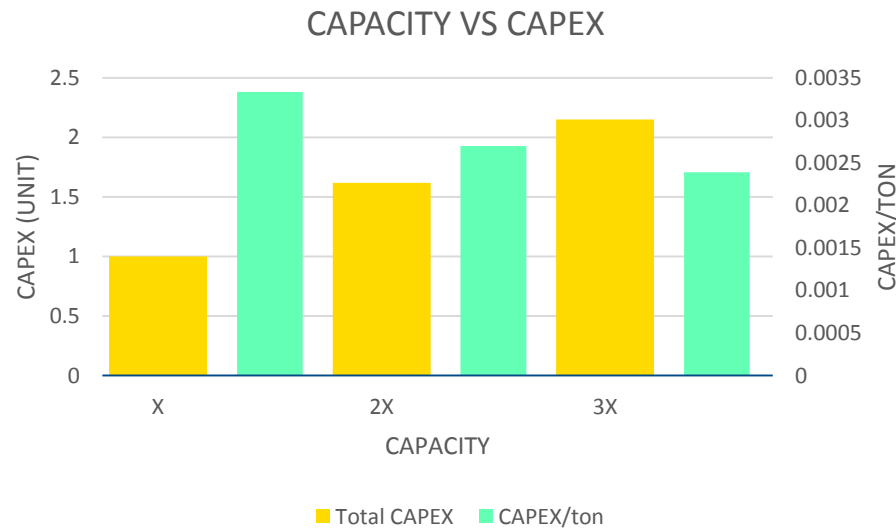
- Reduces capex outflow in one go – may improve cash projections
- Saving in engineering cost
- One solution can be implemented to many locations
- Faster implementation of subsequent units
- Provide flexibility to respond to varying feedstock
- Respond to future demands
- Common spares – saving cost on capital spares
- Repeat implementation – faster and error free
- Operator trained in one unit well suited to handle other units
- Possibility to bring new improvements in subsequent units

Disadvantages of smaller capacity units

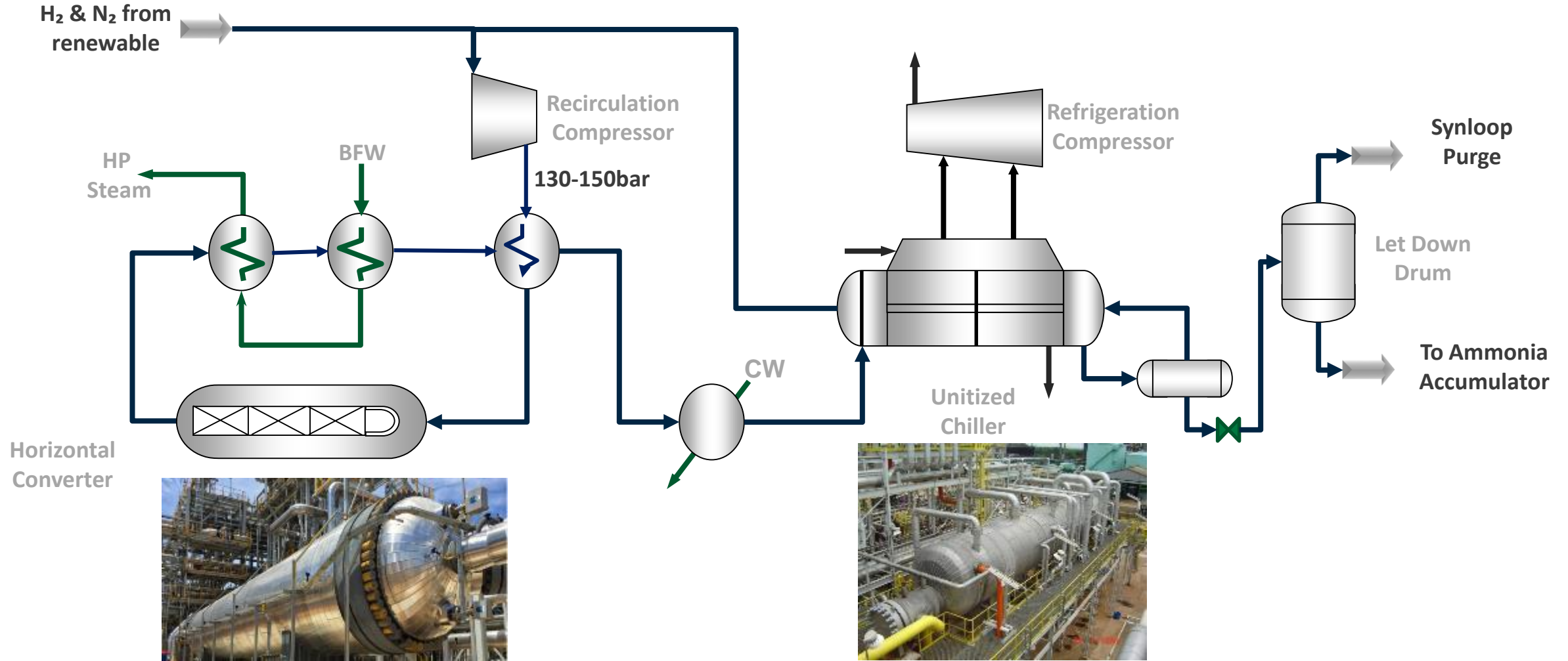
- More number of unit - higher is equipment count and higher is maintenance
- Higher manpower required to operate more units
- Higher overhead cost
- Multiple hazard sources
- High demand of Green Ammonia
- Higher CAPEX

How Does Cost Changes With Plant Capacity

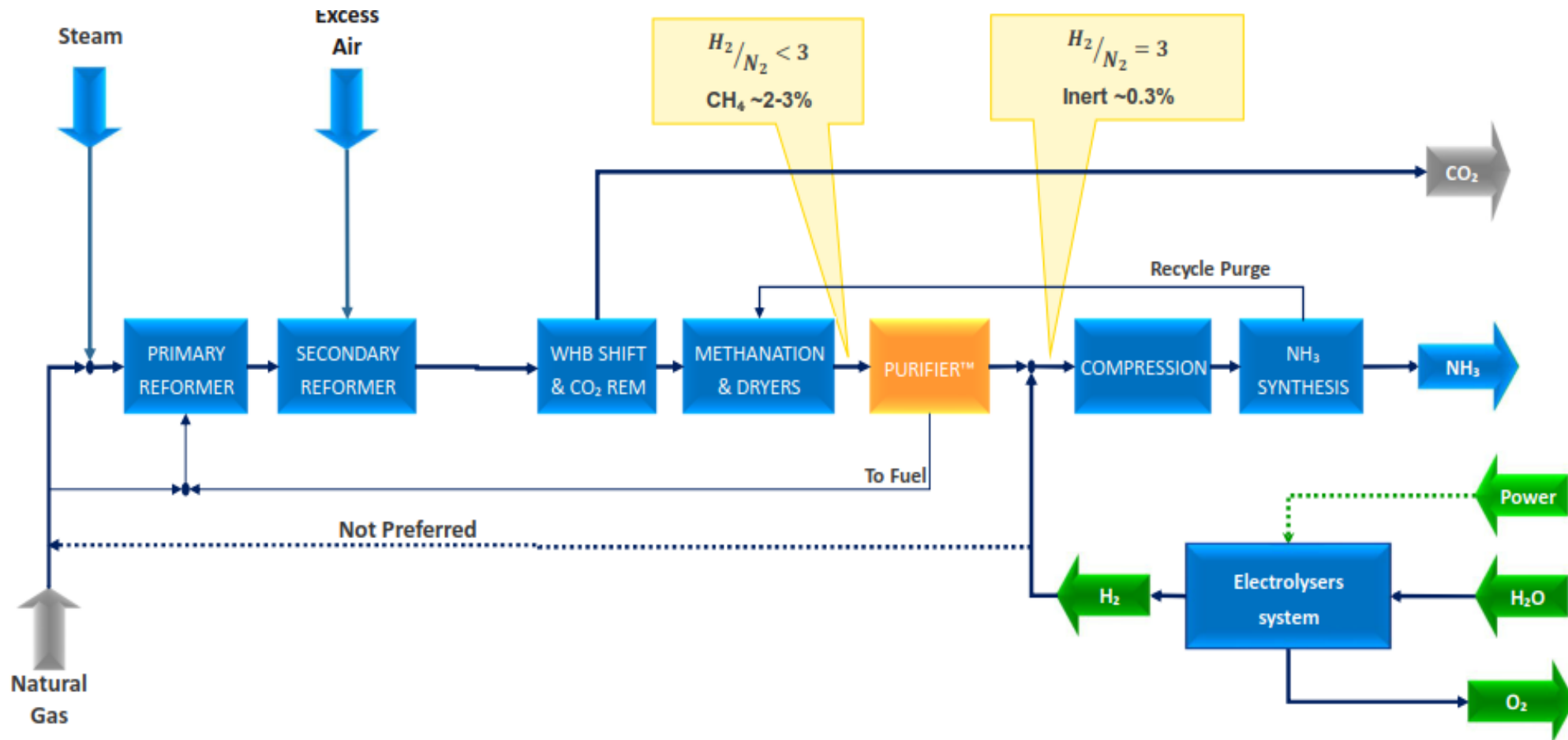
- Ammonia unit are designed for specific capacities including all element in it
- No equipment is multiplied for achieving capacity
- Ammonia synthesis loop can be designed upto 6000 MTPD without need of parallel operating equipment
- So, it provides advantage of economy of scale as capacities are increased

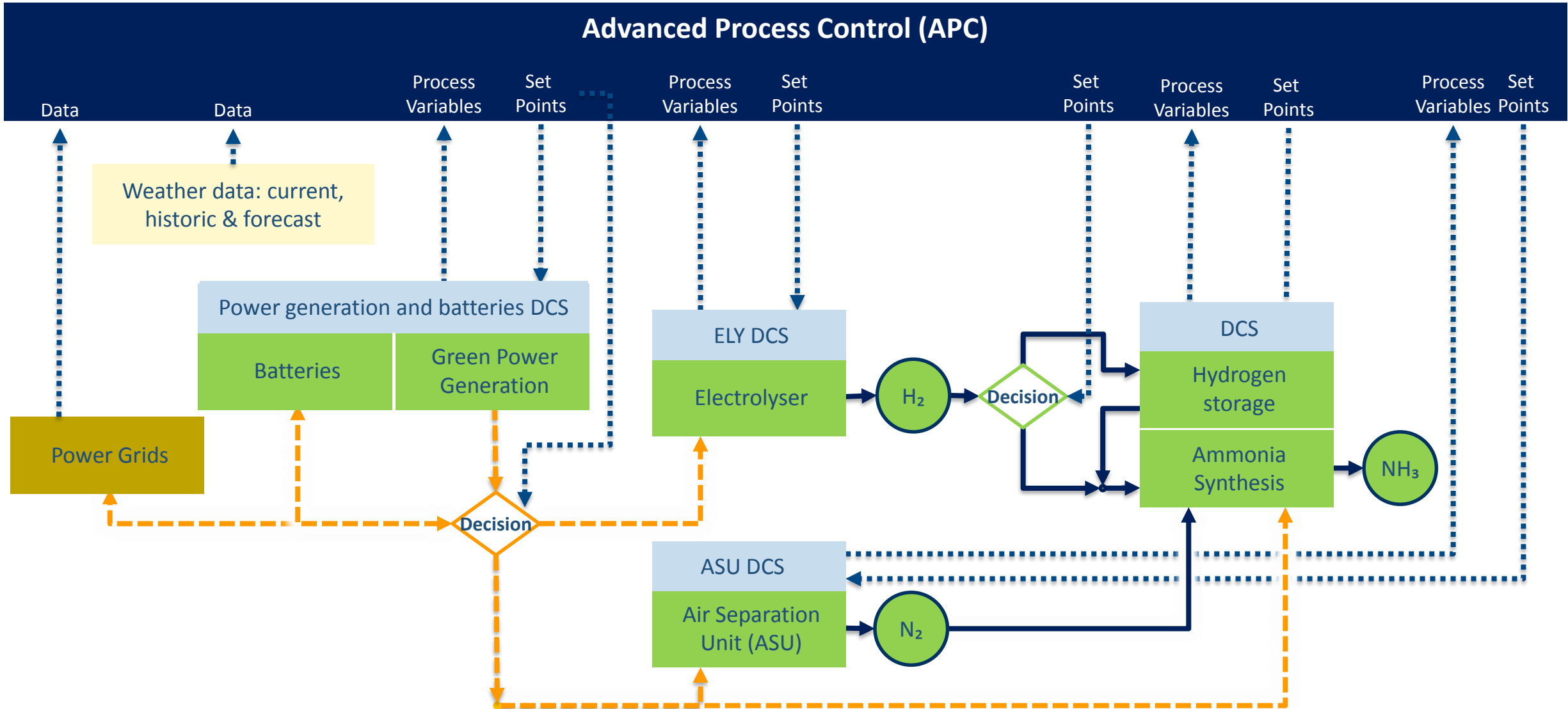


Unsurpassed Ammonia Synthesis Reliability, With Lowest Energy Consumption at Lower Capital Cost (Less Equipment)

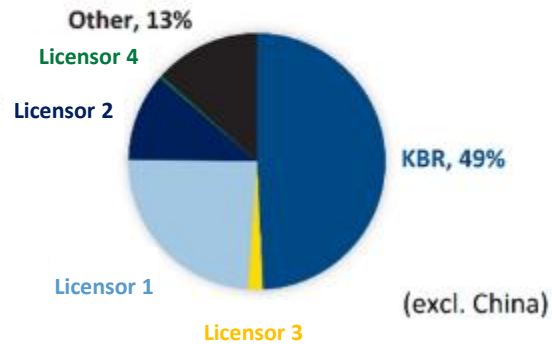


Side Stream Electrolyzer System for Ammonia Plants

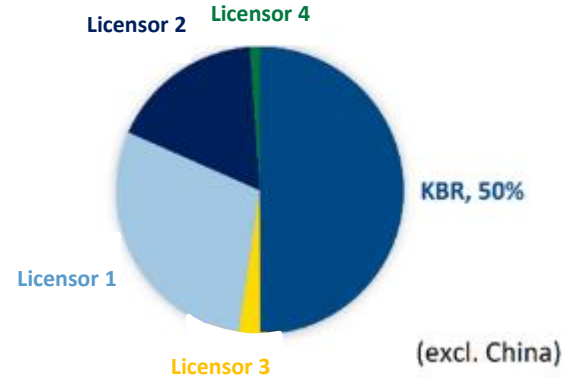




AMMONIA CAPACITY MARKET SHARE (SINCE 1944)



AMMONIA CAPACITY MARKET SHARE (SINCE 2010)



- KBR: \$7.3B revenue in 2021, 29,000 employees, 80+ countries
- Licensed 250 grassroots ammonia plants since 1944
- Half of global ammonia licensed from KBR technology to deliver:
 - Lowest CAPEX
 - Lowest OPEX
 - Lowest Downtime
- *KBR frontrunner in optimizing energy efficiency, ensuring continuous steady state operation, thus minimizing CO₂ emission*



Recent Highlights

World's **largest** ammonia plant with single converter currently operating over 3,000 MTD EuroChem, Russia

World's **most energy efficient** ammonia plant
6.27 Gcal/MT (22.6 MMBTU/ST), Chambal, India

World's **most reliable** Ammonia plant
2,162 consecutive days in operation (almost 6 years) at Yara, Netherland

Monolith Materials **Zero-CO₂ emissions**
930 MTD ammonia operation range 30% to 100%, in Hallam, Nebraska, USA



Green ammonia makes headlines for its pivotal role in

- decarbonizing the fertilizer industry
- global energy transition towards lower/zero carbon fuels

Green ammonia offer huge market growth potential as green hydrogen transport vector, shipping fuel and direct energy source

There is not a single generalized solution, it depends on specific requirements

Deep Turndown and fast response will lead to lower CAPEX

K-Green Technology can offer tailor-made solutions providing higher flexibility & maintaining same reliability

KBR, world leader in ammonia technology, offers complete solution for blue and green ammonia. Up to 6,000 MTD in a single converter