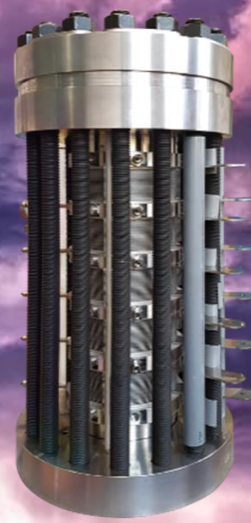
Cost effective hydrogen processing technologies

Introduction HyET Hydrogen
June 2020



HyET Hydrogen
Efficient purification & compression

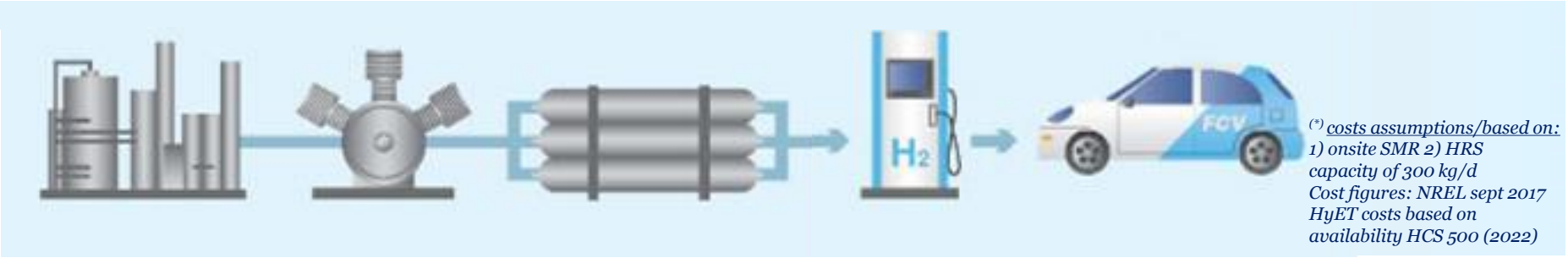
HyET
High Yield Energy Technologies

HyET Hydrogen forms part of the HyET group of companies

Value proposition

HyET's **Electrochemical Hydrogen Processing (EHP)** technologies can significantly lower **CAPEX** and **OPEX** of the H2 supply chain for many existing **industrial H2 markets** as well as for the upcoming **FCEV markets**.

Example: Electrochemical Hydrogen Compression offers important cost and other operational advantages for application in HRS (e.g. increased reliability, silent operation, flexibility, compactness, 20 years system lifetime (no moving parts).



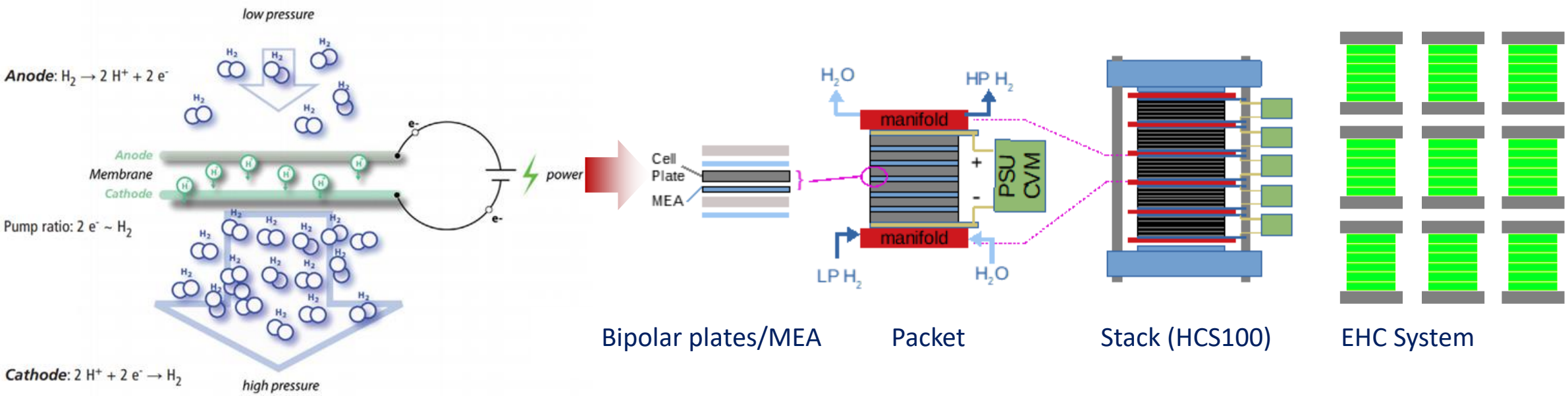
(*) costs assumptions/based on: 1) onsite SMR 2) HRS capacity of 300 kg/d Cost figures: NREL sept 2017 HyET costs based on availability HCS 500 (2022)

H2 Generation & Purification | Compression | Storage 875 bar | Dispensing, Cooling & other

	Mech	HyET	Mech	HyET	both	both	Total Mech.	Total HyET
CAPEX ($/ kg/d) (*)	3150	2650	2000 (*)	300 (*)	500	400	6050	3850
TCO ($/kg) (*)	2.05	1.75	1.50 (*)	0.47 (*)	0.66	0.56	4.77	3.44

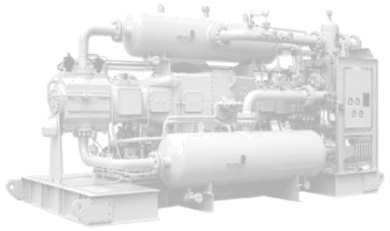
Electrochemical Hydrogen Compression (EHC)

- Isothermal compression -> lowest energy need
- Single stage compression 1 -> 900 bar
- Compression and Purification in one device
- Flow turndown from 0-100% -> fast response
- Flexible capacity by parallel installation -> built-in redundancy
- Can handle water saturated hydrogen -> no upstream dryer needed



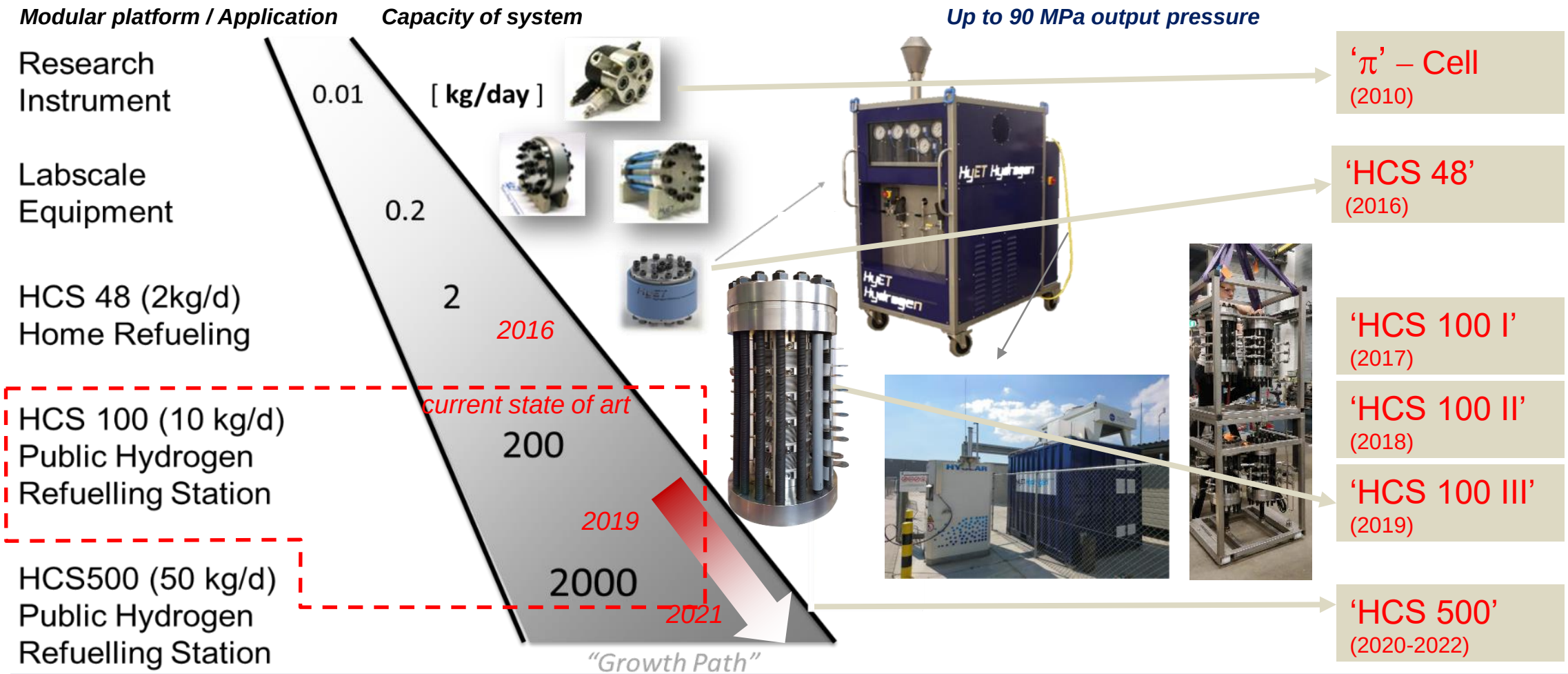
Performance characteristics of EHC

	Mechanical compressor	Electrochemical compressor
CAPEX (USD$/kgpd H_2)	1000 - 1500	150-300 (HCS 500 full series production)
TCO (USD$/kg H_2)	1.0 - 1.5	< 0.6
Energy consumption (kWh/kg)	3 (?) – 7	< 4
Availability (%)	80 (?)	99+ (MTBF > 40000 hrs)
Back up compressor required	Often: Yes	No
Scalable	No	Yes
Silent	No	**Fully Silent**
Compact	No	Yes



Compact & no moving parts…

HyET EHC technology evolution



HyET EHC system evolution

10” cabinet
2 kg H2 /day
400 bar discharge

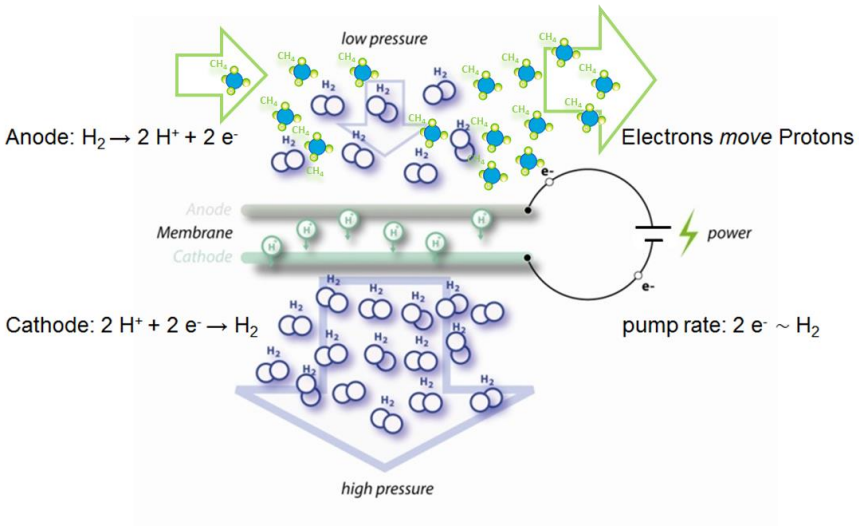
19” cabinet
10 kg H2 /day
875 bar discharge

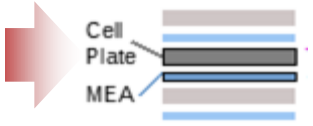
10 ft. container
120 - 200 kg H2 /day
450/ 875 bar discharge

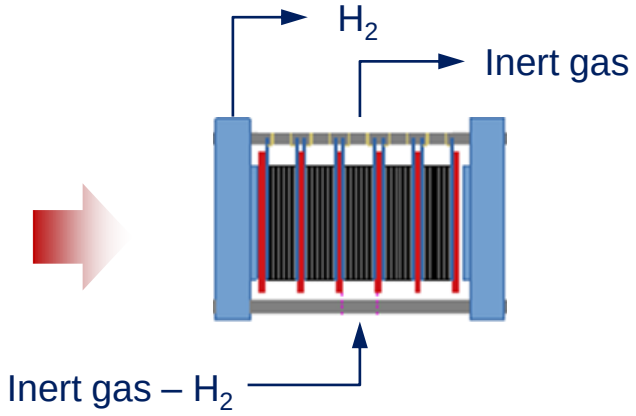
20 ft. container
500 – 2000 kg H2 /day
450 / 875 bar discharge

Electrochemical H2 Separation: Operating principle

- Cost effective extraction of H2 from carrier gases using Membrane Electrode Assemblies (MEA)
- Carrier gases (N2, He, CH4) cannot pass the MEA and leave the anode outlet
- Hydrogen gas is selectively dissociated and is transported through the MEA and leave cathode outlet
- High purity (99.999%) hydrogen can be produced.
- Hydrogen Purification Stacks (HPS) are installed as spool piece internals
- Optionally: Purification/separation and compression in one system





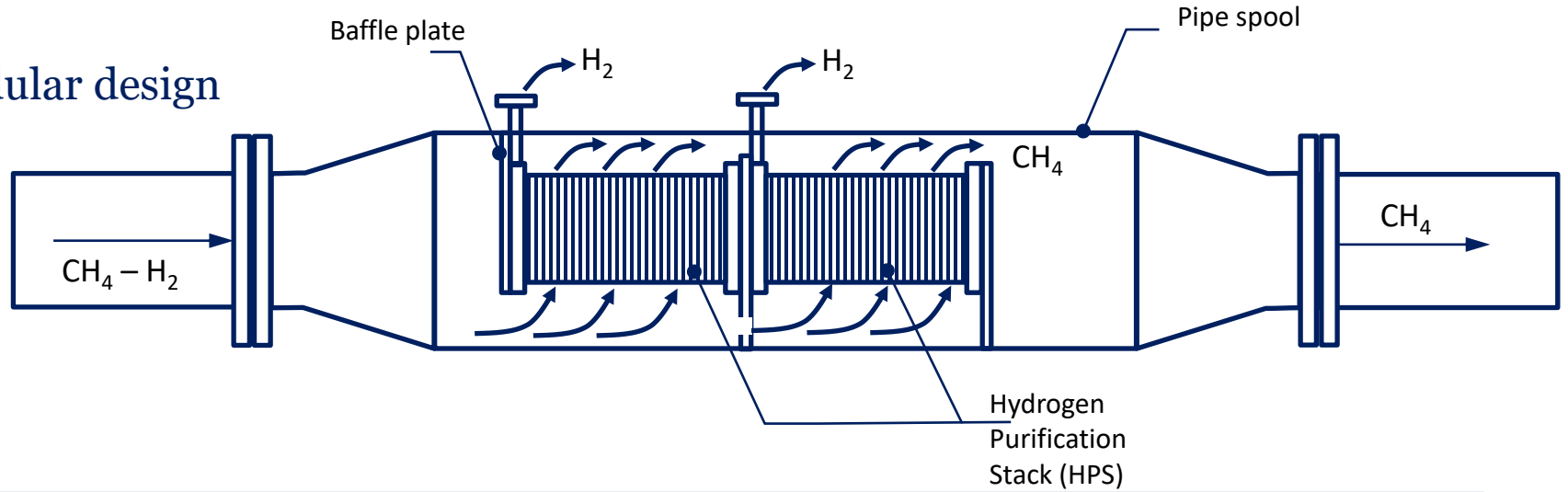


Bipolar plates/MEA

HPS internal (open anode)

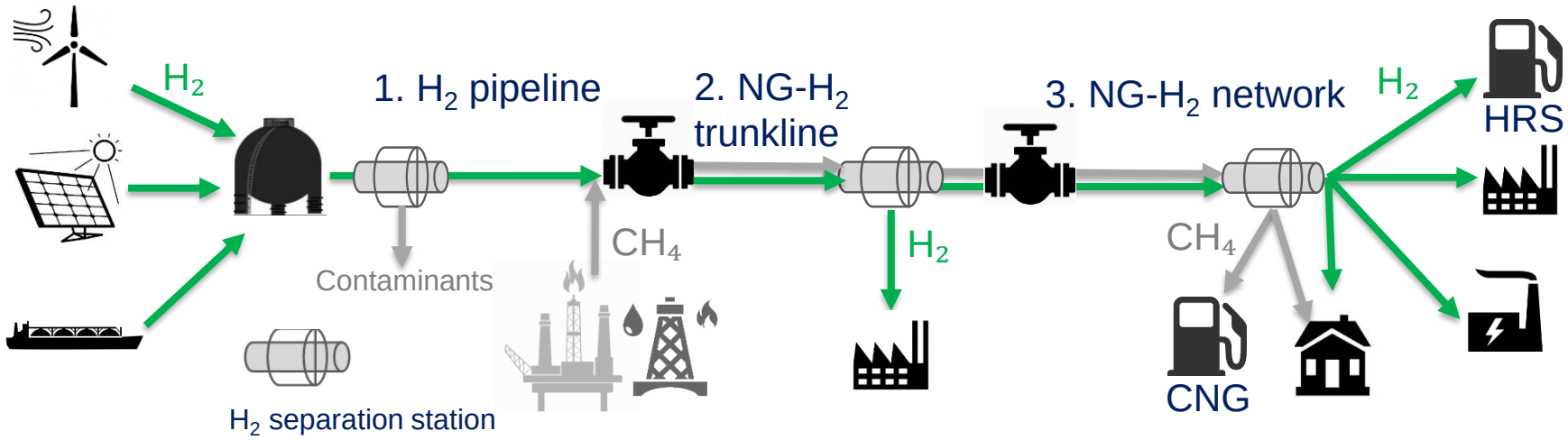
Benefits of Electrochemical H2 extraction

1. **Very cost competive:**
   Hydrogen Purification/Separation Stacks (HPS) are installed as low dP separation internals in a Pipe Spool
2. **High energy efficiency and separation efficiency**
   Proton Exchange Membranes are highly selective for H_2
3. **Low OPEX**
   Static equipment → high reliability → low maintenance
4. **Flexible operation**
   Full flow turndown → Modular design



H2 extraction from gas network

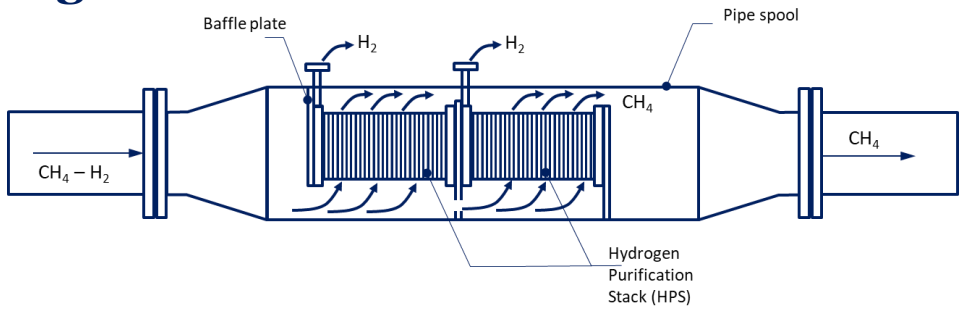
1. **Transport of 98% H_2 through HP transmission pipeline**
   Separation station 1: Removal of impurities to make 99.999% H_2
2. **Transport of blended H_2 in HP natural gas trunkline**
   Separation station 2: Extraction of H_2 for large industrial end-users
3. **Distribution of blended H_2 through LP networks**
   Separation station 3: Extraction of H_2 for HRS, small industry and domestic



Electrochemical H2 processing

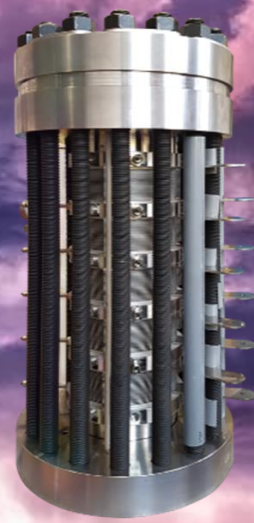
1. **EHC systems offer the best operational performance for high pressure hydrogen storages.**
   - OPEX cost 0.30 – 0.60 USD /kg
   - Availability >99%
   - Safe, silent and intrisically reliable

2. **EHP systems efficiently extract hydrogen from gas pipelines enabling a smooth transition from natural gas to hydrogen**
   - OPEX cost USD 0.50 – 0.70 USD /kg
   - Produce fuel cell grade Hydrogen at high pressure
   - Energy efficient
   - Compact modular design in a pipe spool



HyET Hydrogen

Leader in Electrochemical Hydrogen Processing



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