Global carbon capture technology development updates

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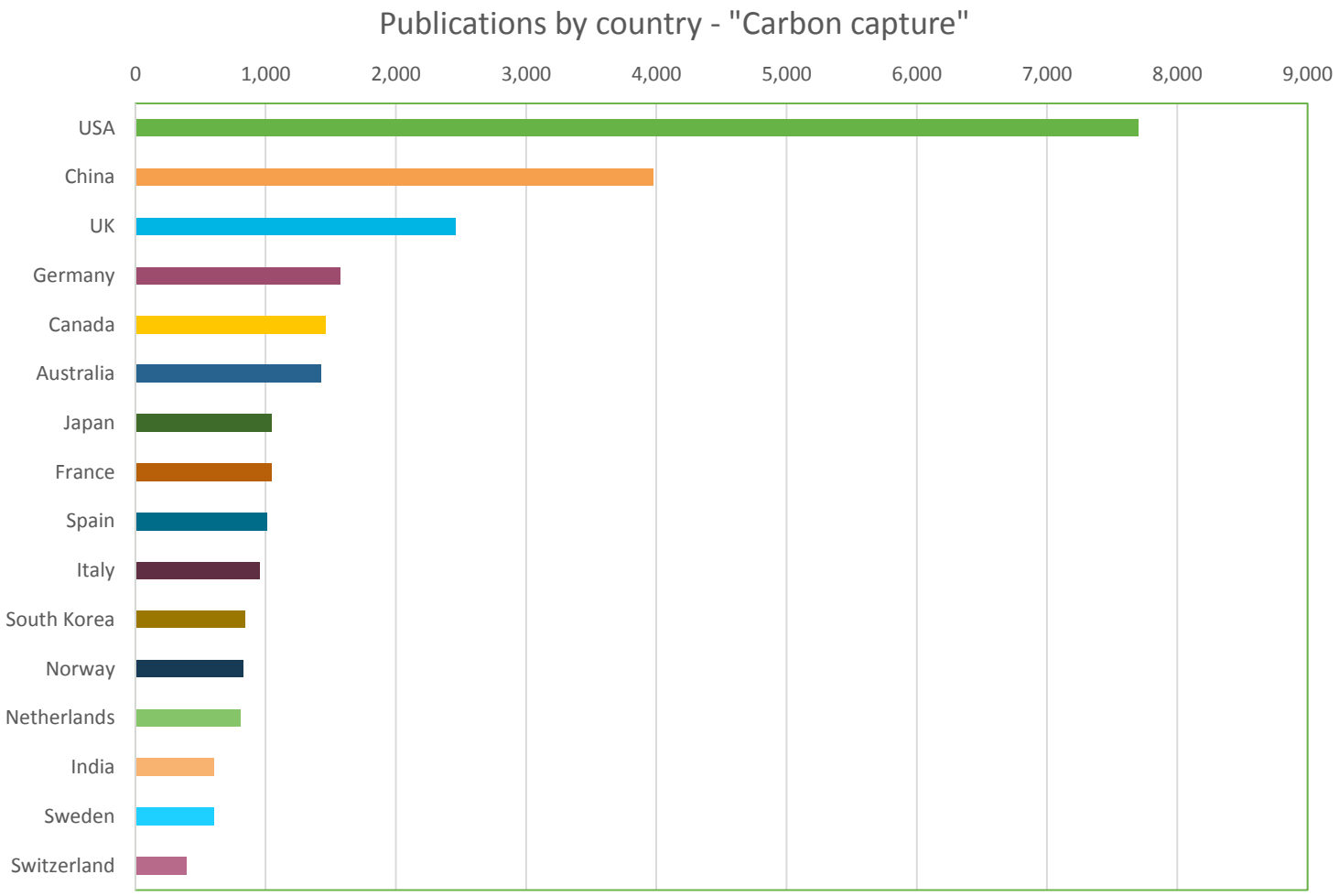
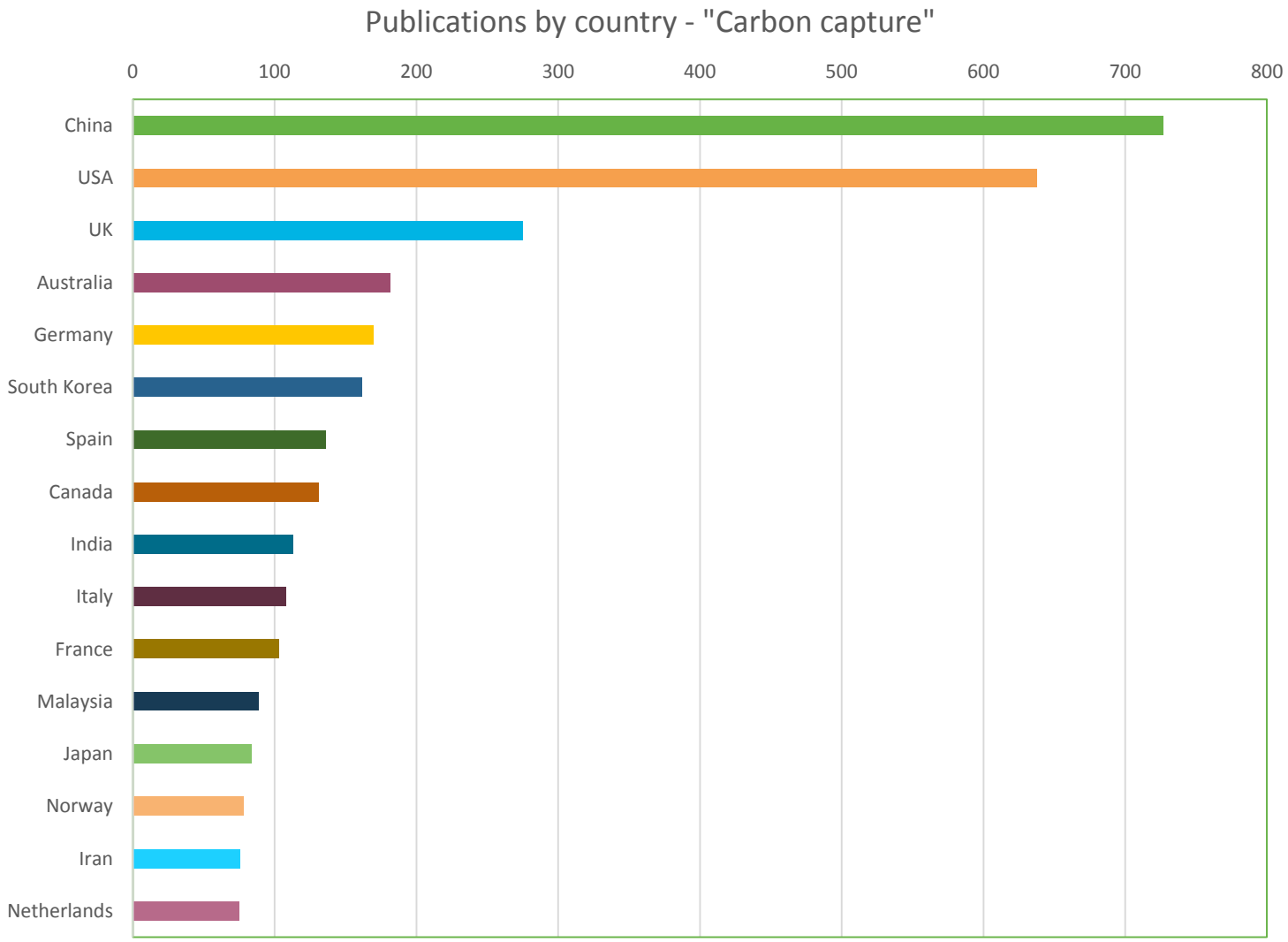
Content

1. Carbon capture technology development across countries
2. Reflections on today’s carbon capture technology
3. Some thoughts for future development

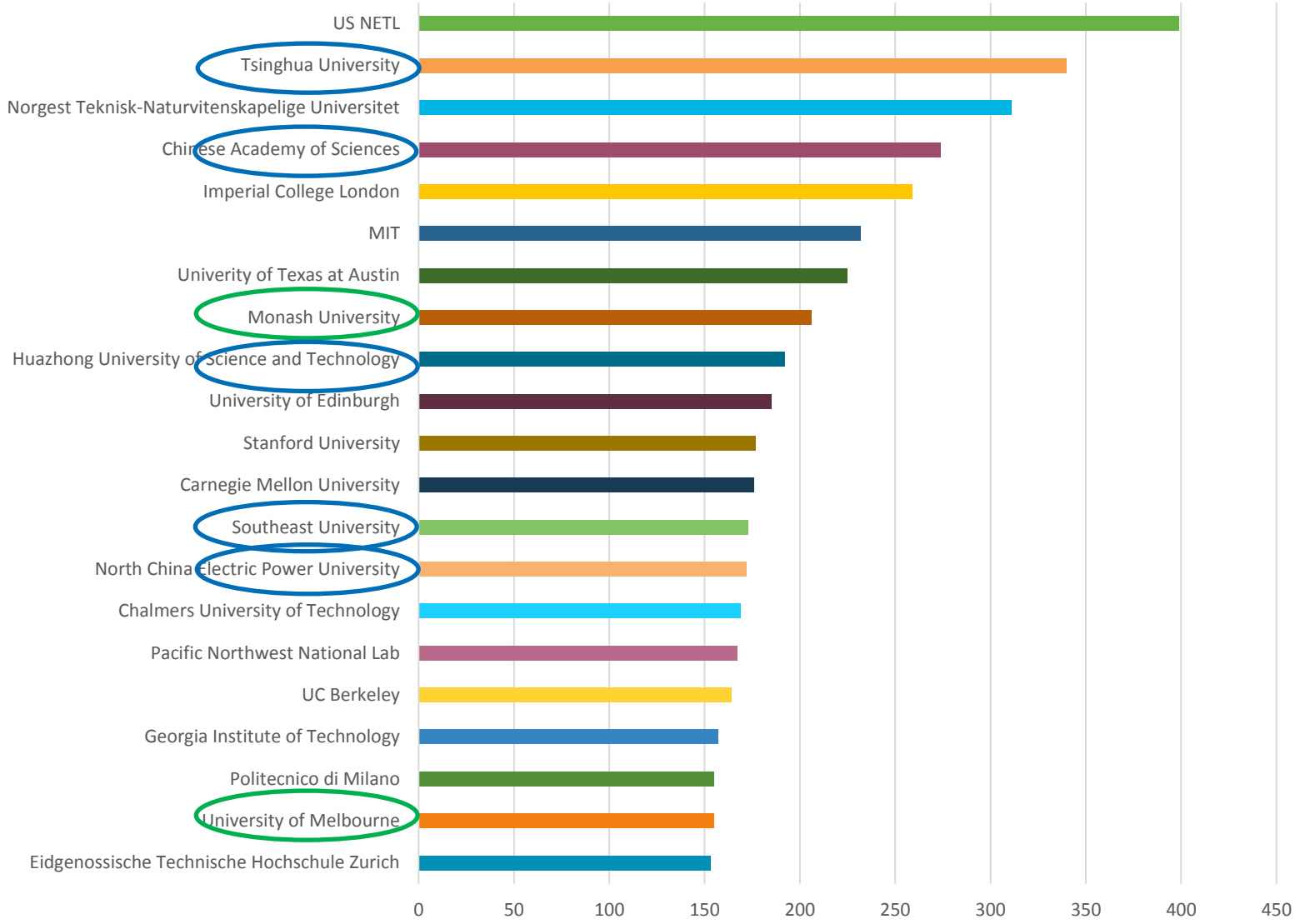
Carbon Capture R&D Ranking – All time



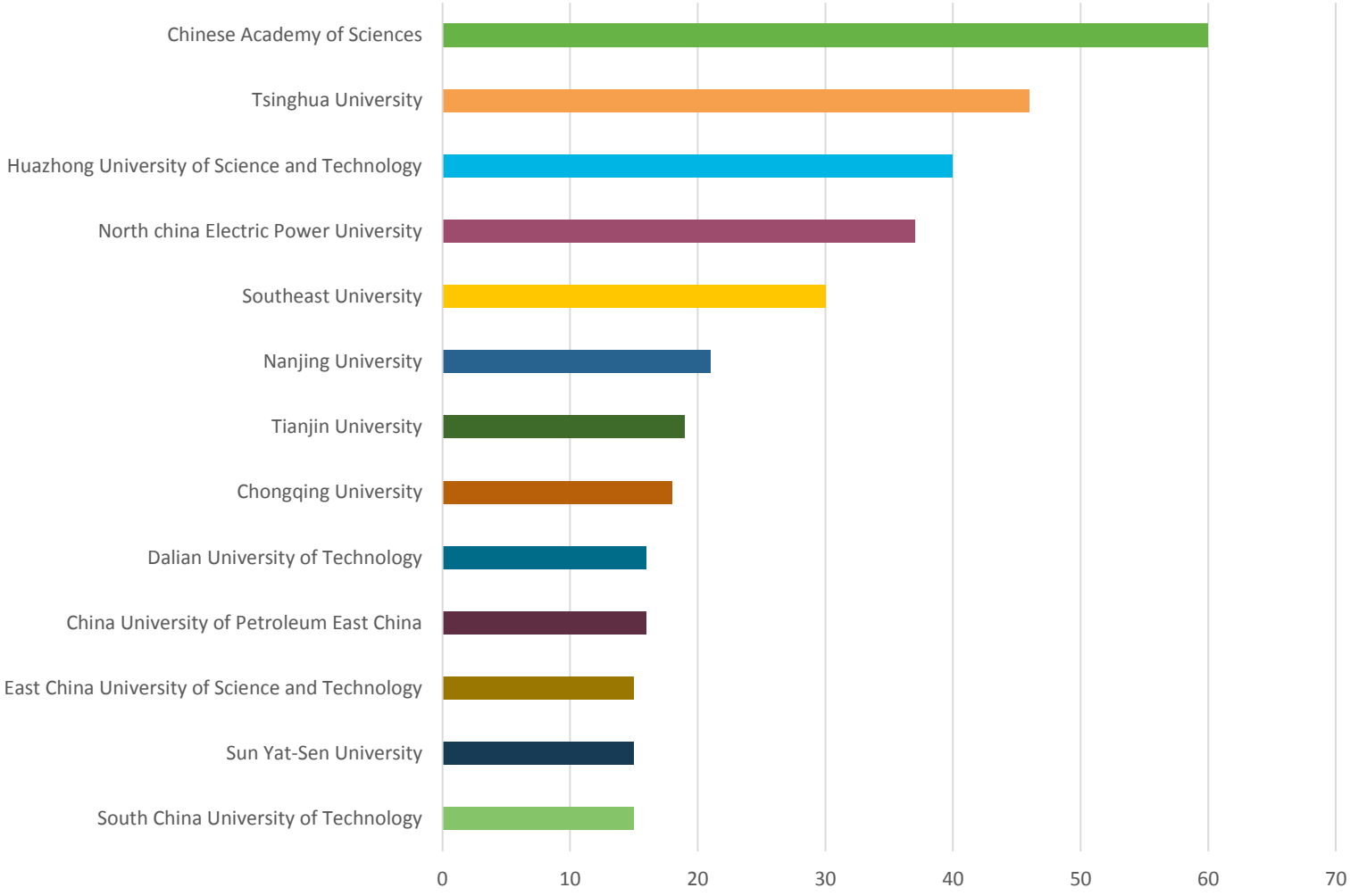
Carbon Capture R&D Ranking – 2016



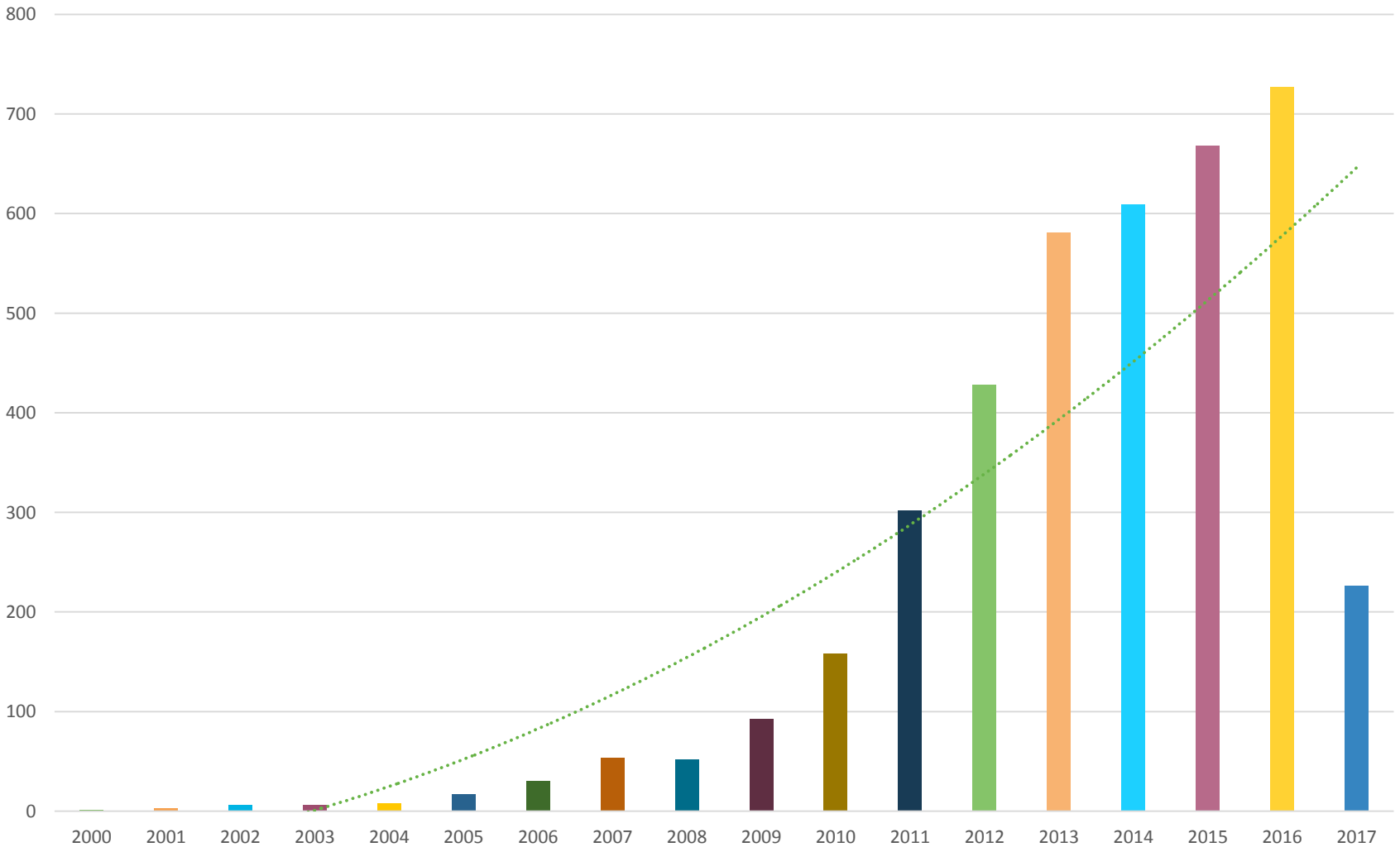
Carbon Capture R&D Ranking – Institutions



Carbon Capture R&D Ranking – China 2016

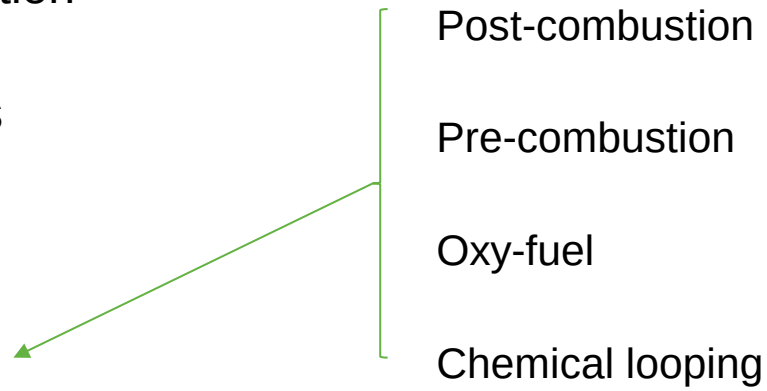


Carbon Capture R&D – China growth



What is carbon capture?

- Intrinsic process
  - Natural gas processing
  - Fertilizer production
  - Coal to products
- Add-on process
  - Power industry
  - Steel Industry
  - Cement Industry
  - Paper and Pulp Industry



Carbon capture technology – where we are?

Intrinsic processes are mature and commercially available.

- Physical solvent: typically for gasification process CO_2 removal； natural gas
- Chemical solvent: typically for natural gas processing; H_2 production; fertilizer
- Adsorbent: hydrogen production process
- Membrane: natural gas processing
- Cryogenic: natural gas processing and high purity CO_2 production

Scale-up, different applications, large scale equipment, integration

Norway Gassnova just announced support for cement, fertilizer and energy recovery.

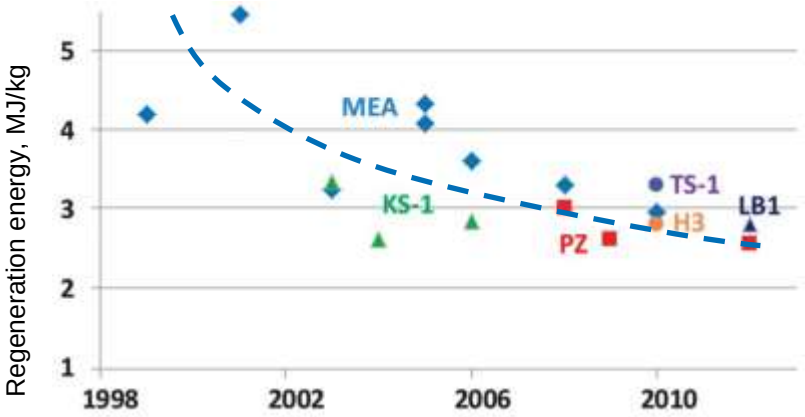
Carbon capture technology – where we are?

The challenges lie in add-on capture processes： energy penalty

- Process integration
- New solvent
- Absorber design(internal structure, packing, cooling etc)
- Reboiler (pressure, temperature, etc)
- Adsorbents (zeolite, carbon, MOF, ZIF，silica）
- Membrane

Carbon capture technology –The Potential

- CO_2 from flue gas (12% CO2 v/v)
- Theoretic energy requirement:: 0.155 MJ/kg
- Practical energy requirement: **2.5**MJ/kg CO_2 capture (thermal energy)
- Current best practice thermodynamic efficiency: **20%**



The role of integration - Air Separation Unit

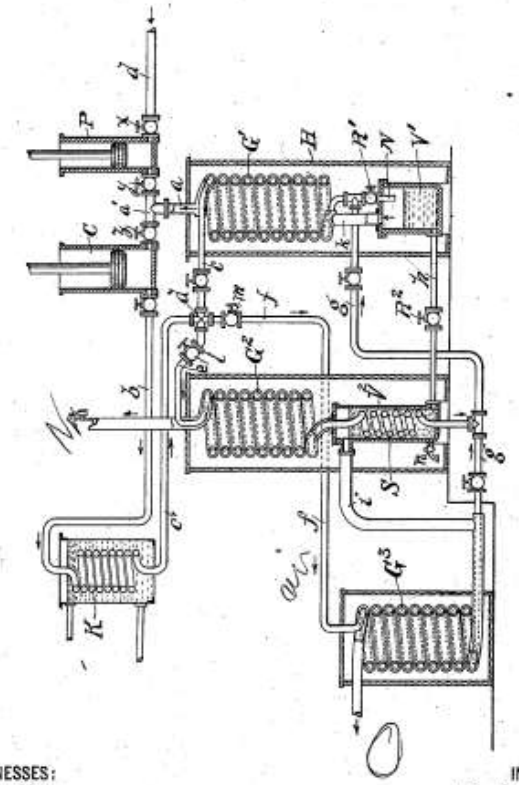
No. 727,650. PATENTED MAY 12, 1903.

C. LINDE.

PROCESS OF PRODUCING LOW TEMPERATURES, THE LIQUEFACTION OF GASES, AND THE SEPARATION OF THE CONSTITUENTS OF GASEOUS MIXTURES.

APPLICATION FILED JULY 9, 1900.

NO MODEL.

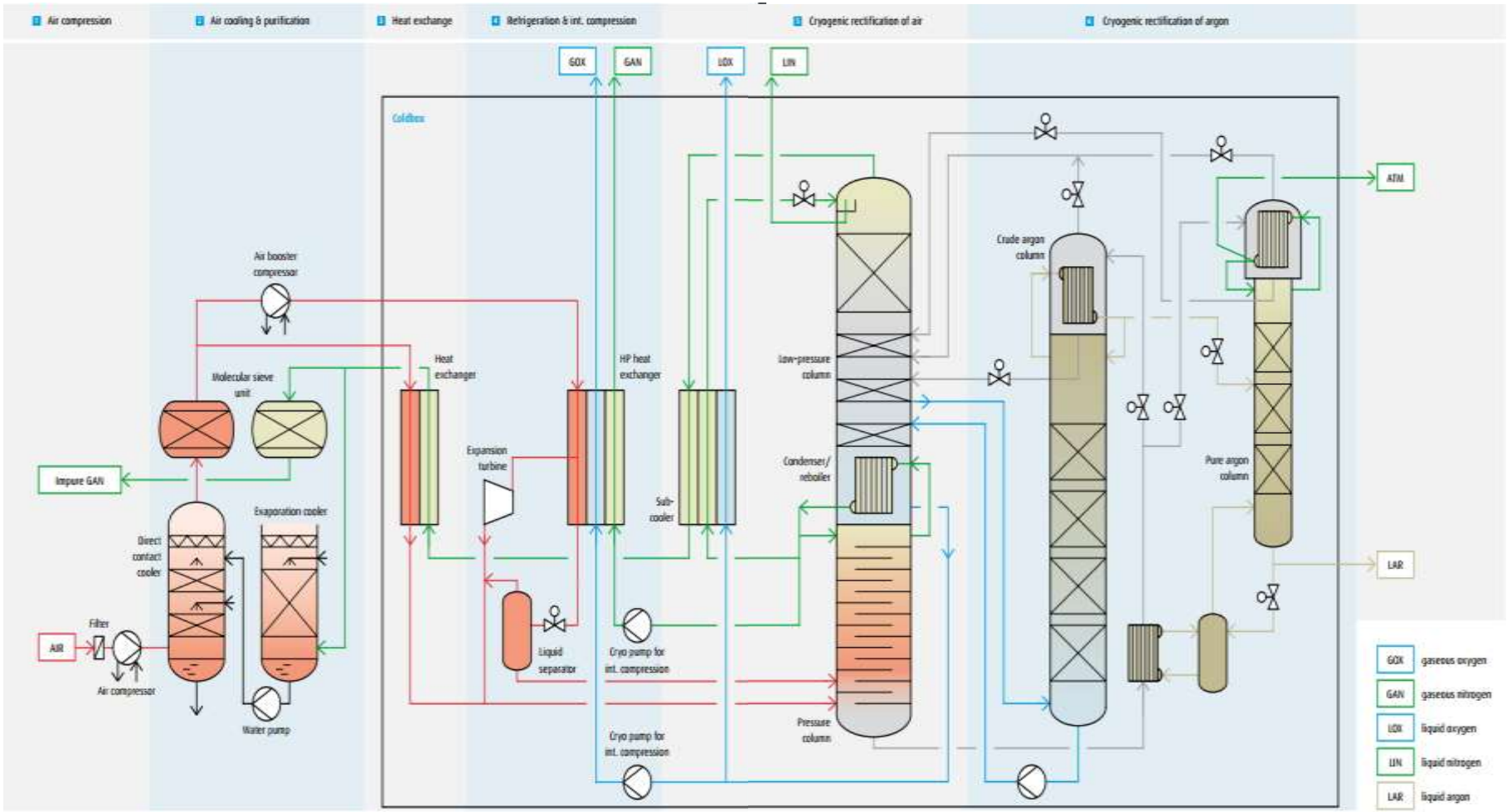


WITNESSES:
Chas. W. Thomas.
Geo. W. Ecculbraum

INVENTOR:
Carl Linde,
BY
ATTORNEY.

5kg/hr O_2

The role of integration - Air Separation Unit



Typical ASU Process today

Petro Nova shows a different model

Petro Nova Project

- No integration with the power station itself
- Steam and electricity from a 80MW gas booster/peaking unit
- Project management
  MHI “Turn-key” project；”making all the calls”

On time, on budget, better than contract performance

The key question to ask is:

i. *How much integration should we have for early projects?*

ii. *How do we strike a balance between CAPEX/OPEX and priority ?*

iii. *How do we cope with the **culture difference** between power industry and chemical/oil/gas industry?*

Modular approach – Shell Quest

- Incremental - less risks for decision-maker “Renewable energy”
- Flexibility - addition of emission reductions with deeper cuts
- Better commercial availability for equipment - no custom made
- Avoid large investment locked in for Gen-1 technologies

Solvents are technically ready but need improvement

Corporations can now sign carbon capture contracts with fixe price, guaranteed performance and schedule. “Turn-key”

- Primary amine: Fluor Econamine
- Secondary amines : DEA
- Tertiary amines: Shell Cansolv; BASF/Linde
- Sterically hindered amines (AMP/PZ): leading candidate, eg. KS-1.
- Ionic liquid, enzyme, inorganic, phase change…

Carbon capture needs all technologies

- All the technologies options we have are important for the deployment of CCS. No silver bullet!
- Choice of technology depends on process, location, availability of utility, expertise, scale, …
- Technologies can learn from each other and grow together.

International collaboration is paramount to the progress of CCS technology.

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