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Theme A6:
CO_2 Transport Infrastructure
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Pipeline Issues

- **Effect of impurities** on physical properties of CO_2 and equations of state impacts pipeline design – pipeline hydraulics, avoidance of hydrate formation & two phase flow etc
- **Transient conditions** (e.g. blow down , start up & shutdown) need special consideration for avoidance of two-phase conditions
- **HSE/ Regulatory/Design codes** issues needs to be defined as it is important in pipeline routing.
- **Risk of long running brittle fractures** (due to cooling effects around leaks) and long running ductile fractures (due to phase changes during depressurisation). Crack arrestors fitted in USA. Impurities?
- **Network** design, development, operation and management (metering & custody transfer etc)
- **Strategy for development of infrastructure** – how much CO2 to collect, when. Top 16 sources account for around 40% of CO2 output

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Offshore Pipelines: Additional Issues

- No experience of transporting CO2 for long distances offshore. The only subsea CO2 pipeline that has been laid is the Snohvit pipeline
- Pressures typically 50 to 200 bar for existing offshore pipelines. Maintaining sufficiently high pressures for delivery specifications could be a problem
- Availability of existing infrastructure- Trunk lines etc
  - Upgrading existing infrastructure for EOR
  - Integration of onshore and offshore networks
  - Decommissioning Vs. Re-use
  - Pipeline integrity and fitness for purpose in re-use
- Hydrostatic pressure may be mitigating factor with regard to brittle fracture
- Impurities introduce variables in most aspects of CO2 transport.

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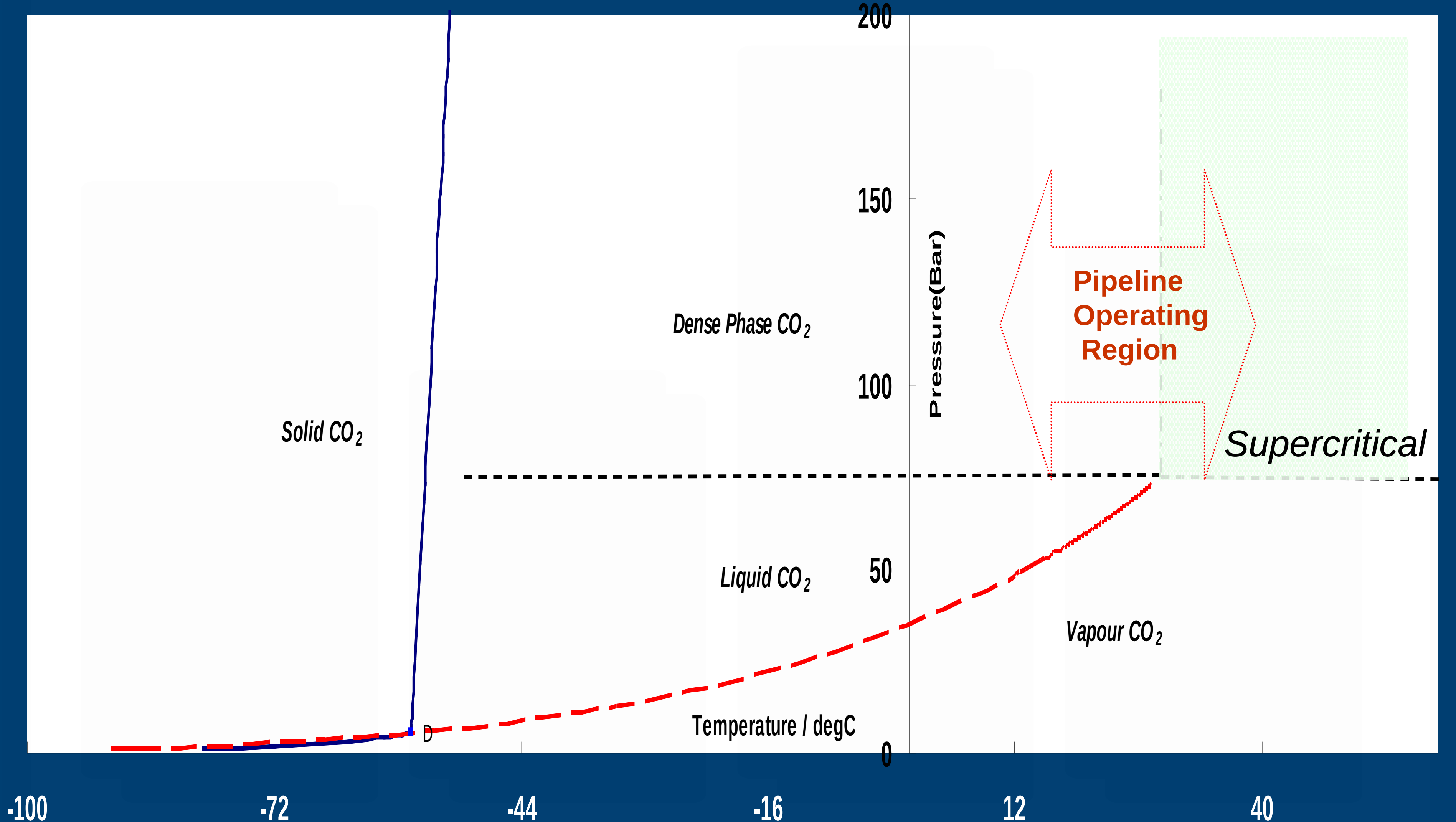
Phase Diagram for pure CO_2



Existing CO2 Pipelines for EOR in the USA:

- **HIGH PRESSURE(140-200bar)**
- **ONSHORE (dessert terrain) and mostly NATURAL sources solely for EOR**

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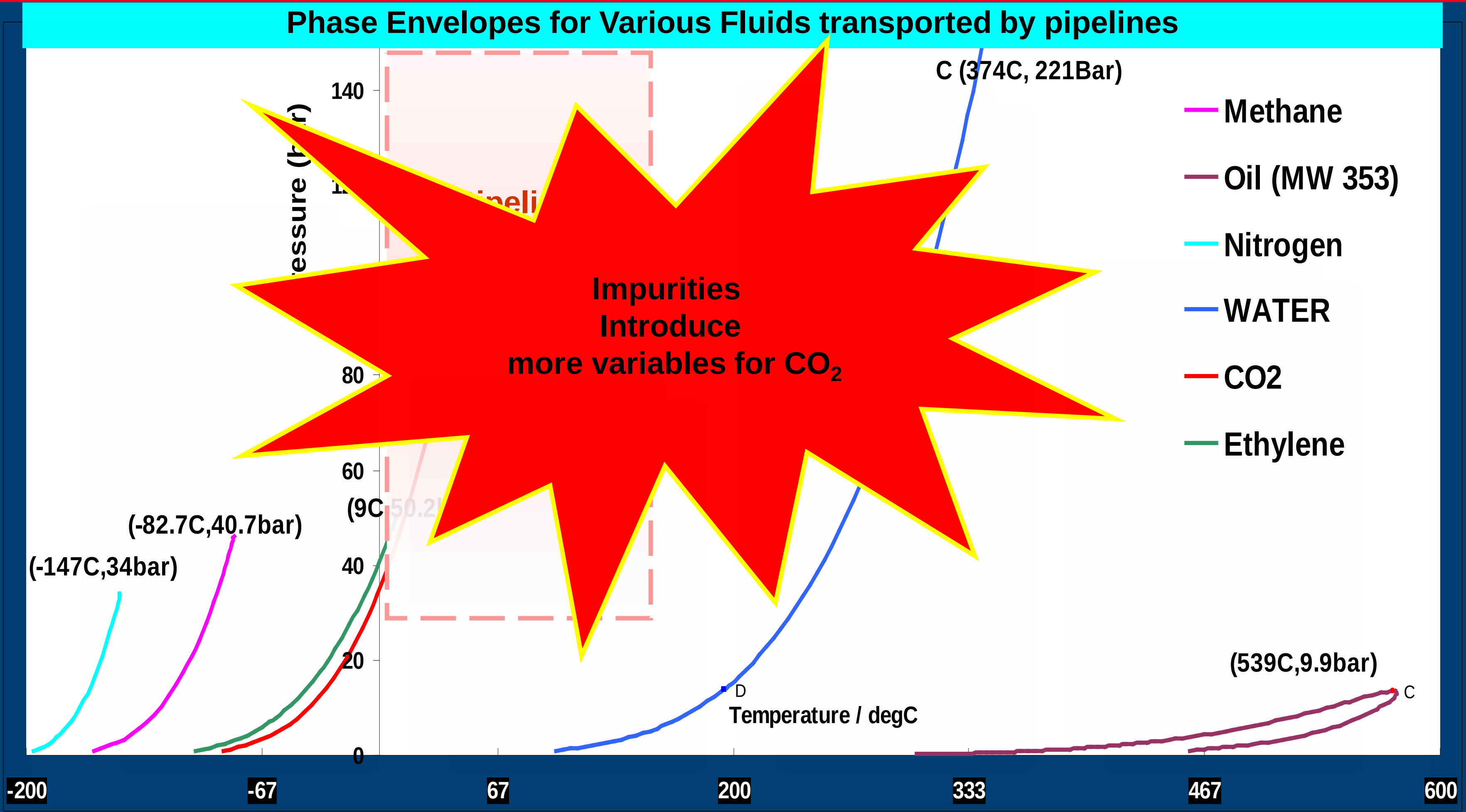
Operating Conditions



CO_2 properties are unusual compared to other fluids transported near the critical point by pipeline:

- Pipeline temperatures for nitrogen and methane are well above their critical point .
- Oil and water operate at pressures lower than their critical values.

No Phase Change

Effect of Impurities on CO_2 Pipeline Transport

- **Pipeline risk modelling**
  - E.g. Dispersion modelling , Health and safety.
- **Hydraulics -** 2 phase flow, transients, hydrates , pipeline capacity and compression
- **Non metallic components**
  - **Elastomers. CO2 diffuses into elastomers under pressure and pressure release may cause explosive decompression and blistering." All elastomers are permeable to CO2"; use high durometer elastomers (>90).**
  - **Pipeline Inspection Tools**

  Impurities could potentially change the diffusion characteristics.
- **Fracture due to slow decompression wave speed. The Decompression characteristics depend on gas composition**
- **Impurities affect water solubility and consequently corrosion.**




- **Power station impurities such as SOx, NOx and Ar have not been transported**
- **EOR and Storage have different requirements.**

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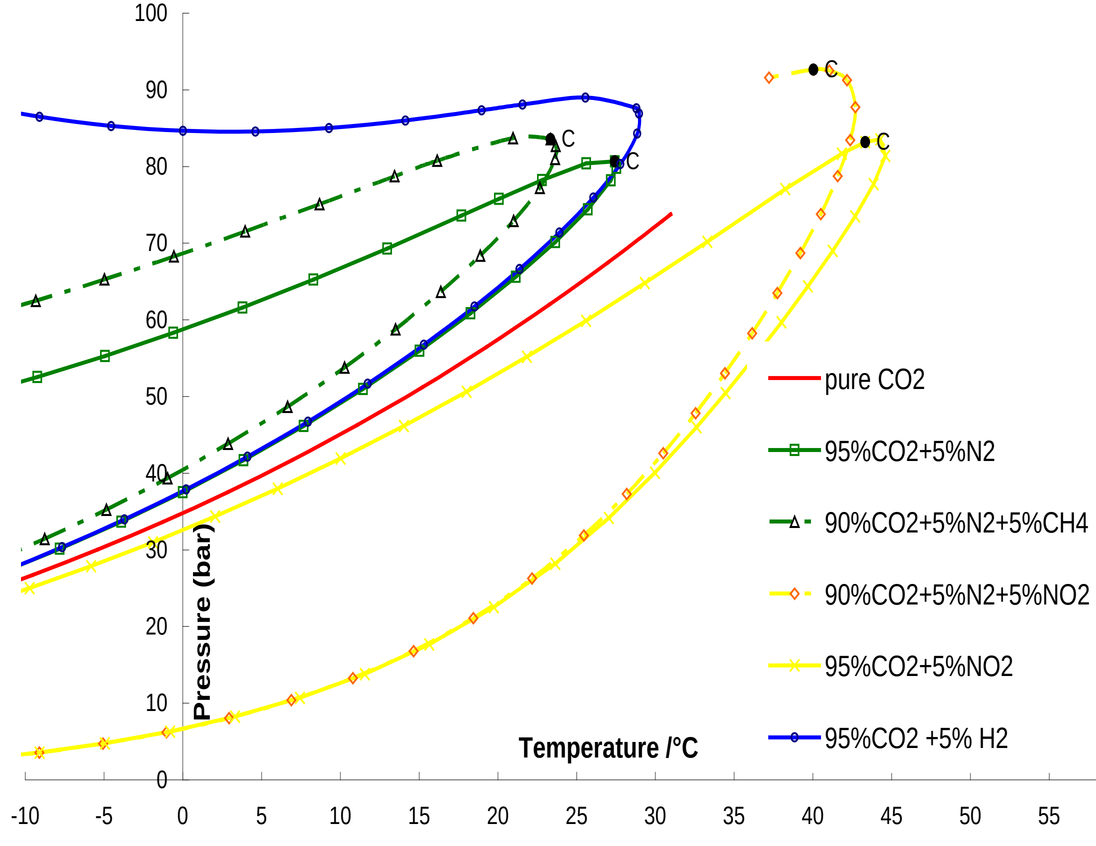
Physical Properties – Phase Envelopes for CO_2 with Impurities

- Change in width & shape of phase envelope-2 phase flow region
- Critical temperature and pressure .
- Supercritical area reduction as % impurity increases.
- Impurity Interaction
- Solid Freeze out components (hydrates)
- Liquid region reduction/elimination



Src: US Dept. of Interior

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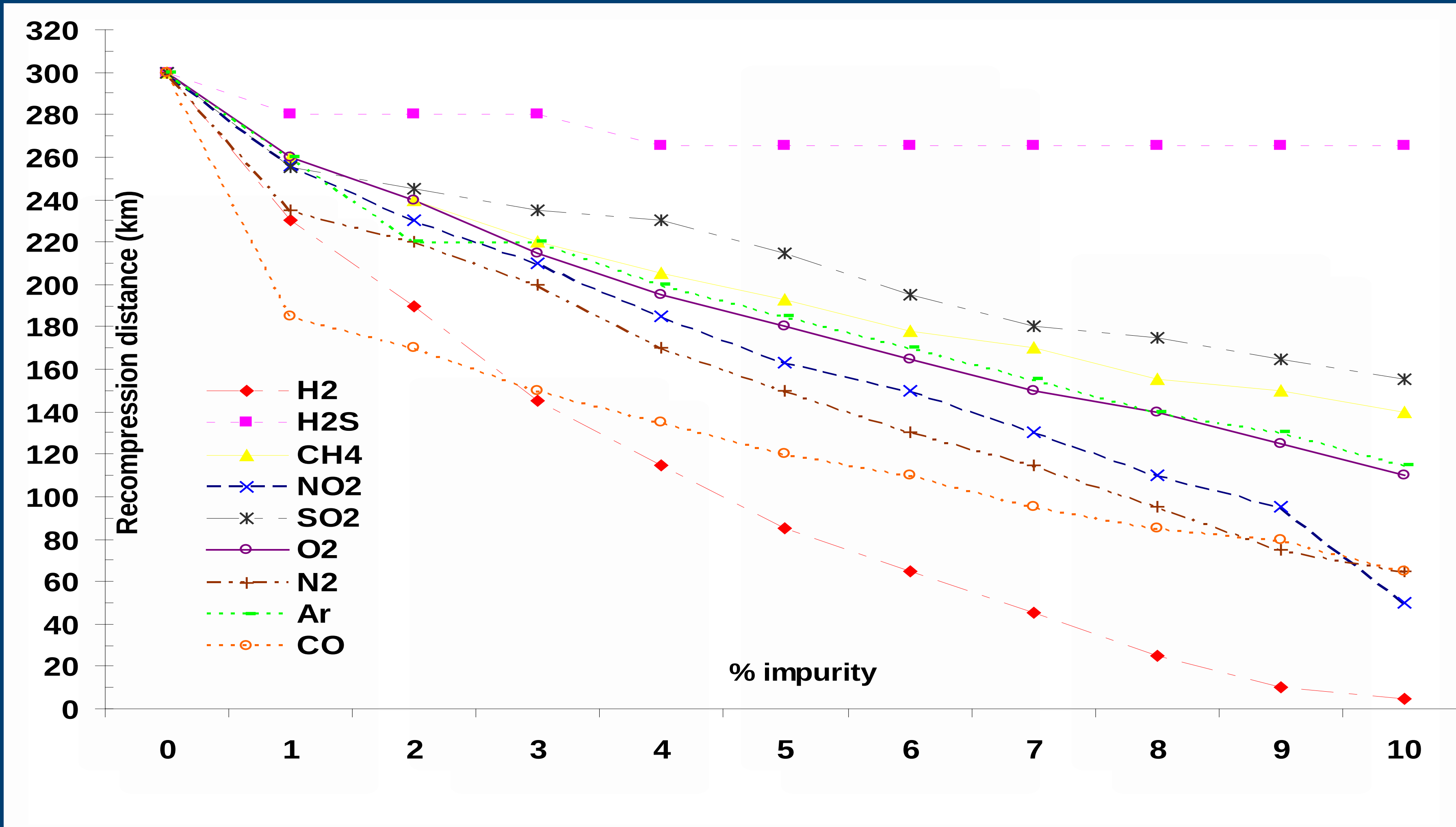
Recompression Distance Vs % Impurity



- 5% H_2 is not economical in terms of number of compressor stations
- Compressor Power is also effected by amount , type and combination of impurities.

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Effect of Impurities on Pipeline Capacity

Composition	Mass Flow rate (kg/s)	Vol. Flow rate (m3/s)	% Deviation from pure CO2	
			Mass Flow Rate	Vol. Flow Rate
Pure CO_2	85.68	108.10	-	-
95% CO_2 + 5% N_2	81.92	44.68	-4.39	-58.67
90% CO_2 + 10% N_2	68.65	38.08	-19.88	-64.77
95% CO_2 + 5% CH_4	82.11	45.37	-4.17	-58.03
90% CO_2 + 10% CH_4	78.01	44.56	-8.95	-58.78
95% CO_2 + 5% H_2	76.48	43.17	-10.74	-60.06
90% CO_2 + 10% H_2	56.19	33.22	-34.42	-69.27
95% CO_2 + 5%Ar	83.7	45.02	-2.31	-58.35
90% CO_2 + 10%Ar	80.68	43.63	-5.84	-59.64
90% CO_2 + 5% CH_4+ 5% N_2	77.5	43.63	-9.55	-59.64
90% CO_2 + 5% H_2+ 5%Ar	62.02	35.07	-27.61	-67.56
90% CO_2 + 5%Ar + 5% CH_4	79.32	44.10	-7.42	-59.21

Calculation is done for a pipeline segment with its flow adjusted to operate at a pressure drop of 0.0001bar/m with an internal diameter of 15”(OD=16”) and an ambient temperature of 5℃

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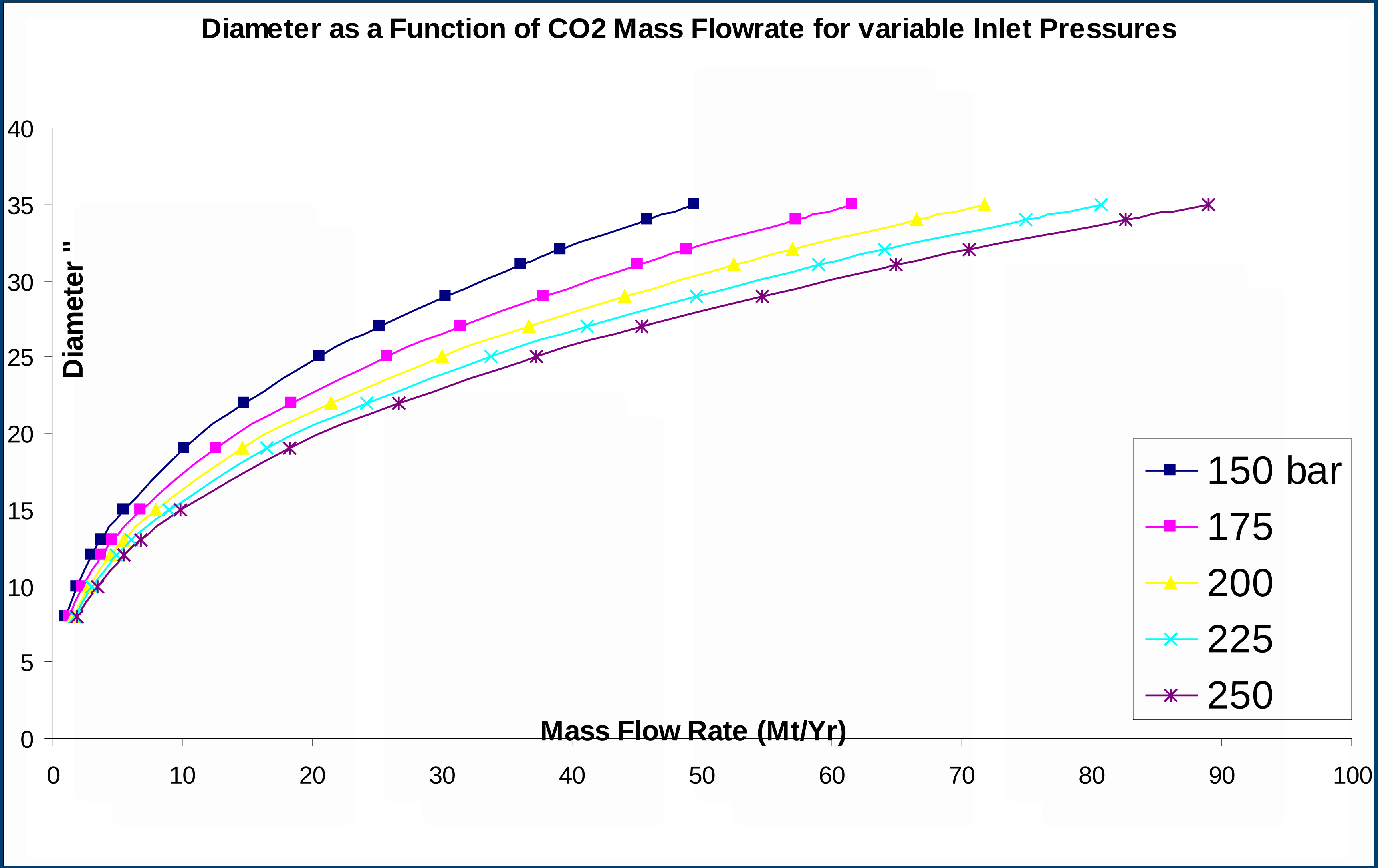

100km CO_2 pipeline with outlet pressure of103 bar.

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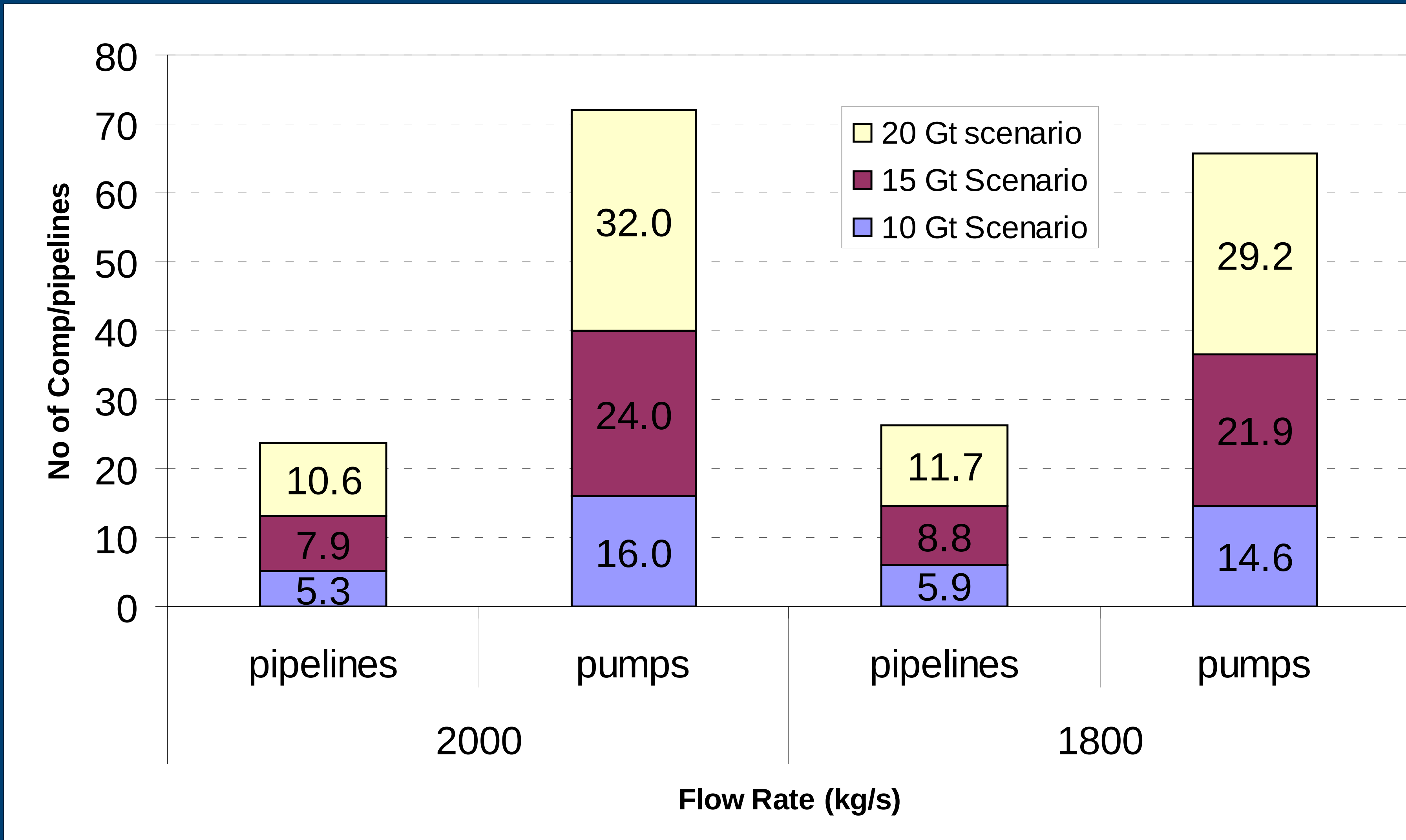
Example 2030-2050 EU scenario



- 40 inch trunk pipelines,250 miles at 100 bar with consideration to erosional velocity pipeline maximum capacity,
- pure CO2 , compression occurs when pressure falls to 80 bar.

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Conclusions

- **Design and operation of CO2 pipelines requires careful consideration due to the unique properties of supercritical CO2 both with and without impurities. The type, combination and quantity affects the physical & Transport properties of CO_2 (density & compressibility - product metering, compression, water solubility and flow assurance affected etc**
- **Recompression Distance ,Compressor power and pipeline capacity are directly affected by the type, combination and quantity of impurities.H_2 having the greatest impact. Offshore costly. Generally, 2-Phase region , Tc & Pc increases with increasing amount of impurities thus reducing operating margin of pipeline. Initial inlet pressure needs to be increased to reduce the number of pumps and compressors**
- **Constraints are placed on CO2 pipeline infrastructure by the requirement to minimize cost, maintain reliability, and sustaining flexibility of operation with changing composition, upsets, sales and supply, the capture of CO2 for sequestration could possibly introduce high levels of impurity to break even between CAPEX and OPEX.**
- **Network analysis, transient flow (particularly from variable sources), flow assurance due to the cyclic operation of power plants and risk assessment will also have to be addressed if CCS is going to be implemented. This work is on-going at Newcastle University.**
- **The infrastructure development varies between scenarios. Important in meeting targets in a cost effectively.**

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Thank You

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Summary of Progress Update at Newcastle.

- Technical & Regulatory requirement (Completed):
  - Fundamental knowledge of hydraulics have been established.
  - Model validation with real-time pipeline data.
  - Regulations and design codes.
- Input data into scenario models which include source and sinks – Transport scenario building (ongoing)
- Identification of sources and sinks - large sources will be chosen. Awaiting input for sinks.
- Material issues
- Network dev. and mgmt
- Existing Infrastructure – availability in the North Sea

Update on analysis and issues...........

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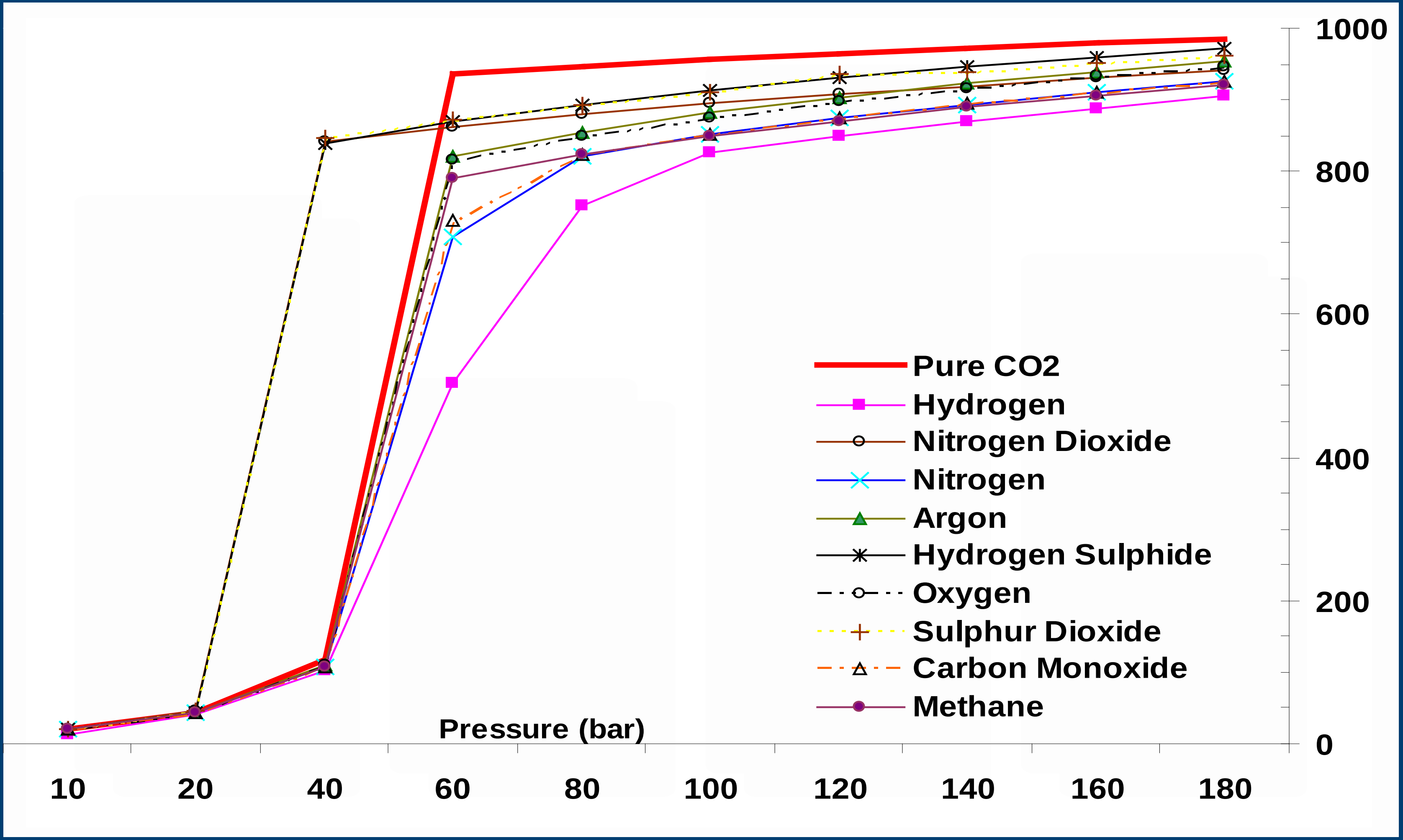
Density – CO2 with 5% Impurity



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