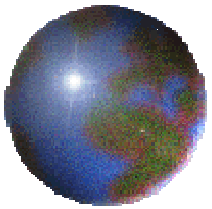

# *Crack Arrestability of High-Pressure Gas Pipelines by X100 or X120*


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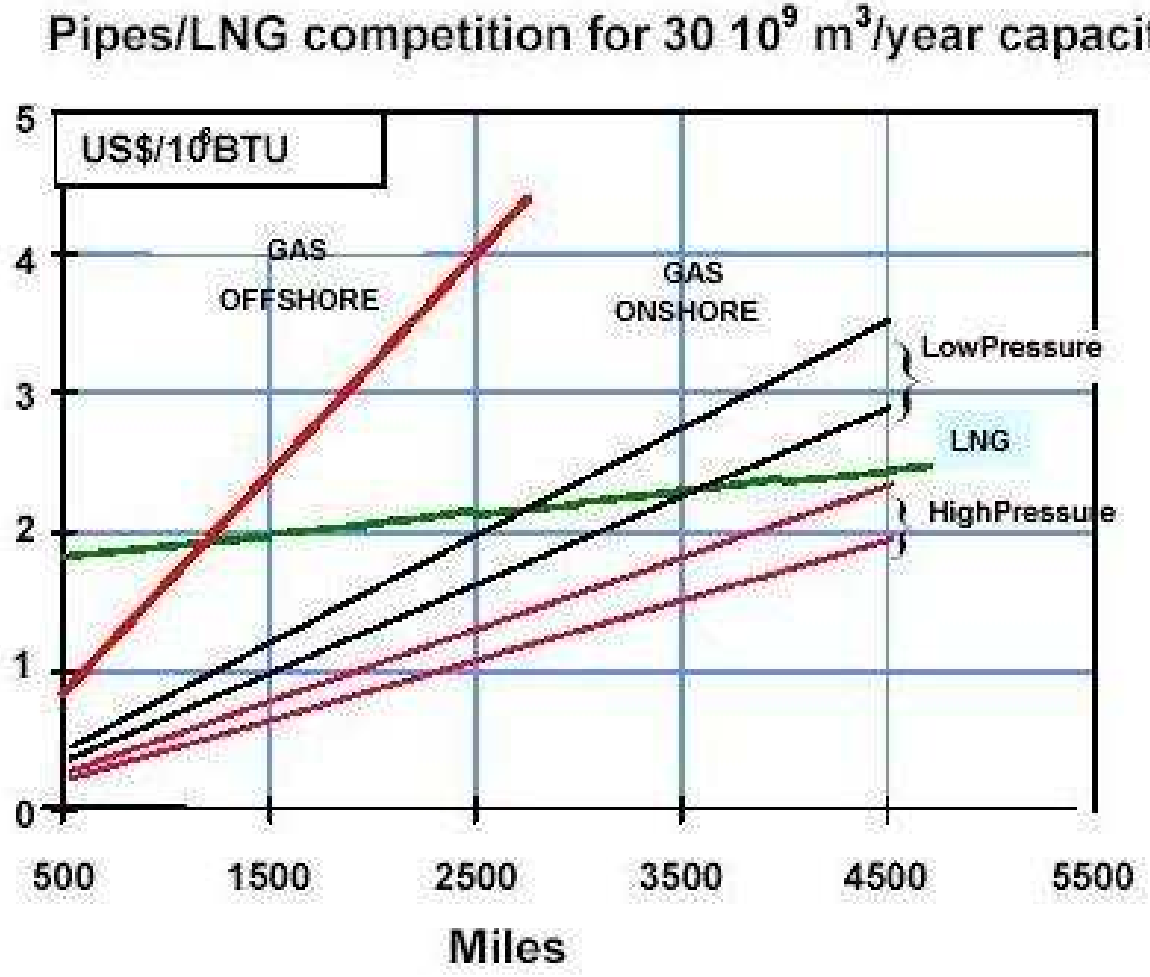
23rd World Gas Conference, Amsterdam, 07 June 2006

# Contents

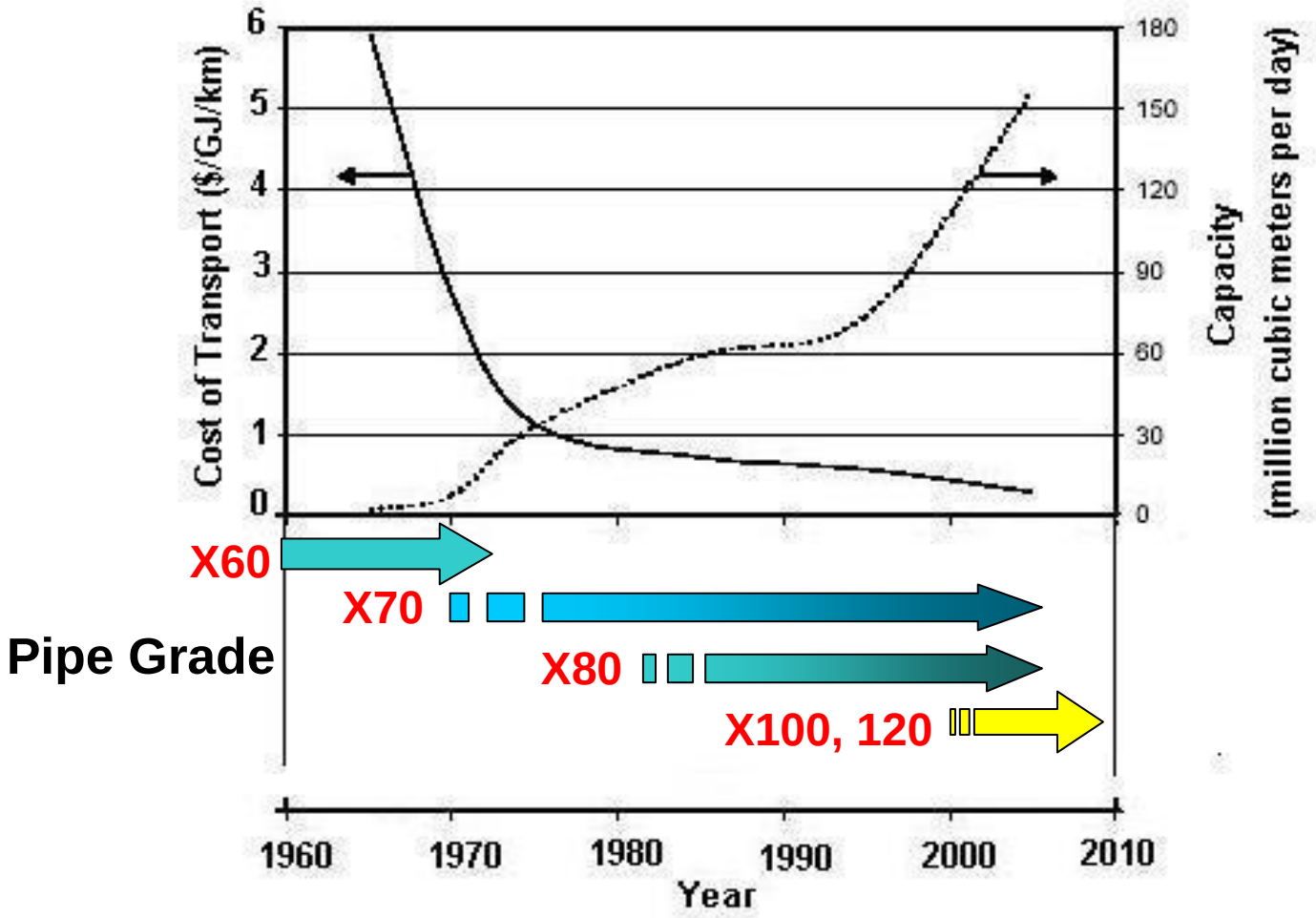
1. Back Ground
2. Development of high strength line pipes for high pressure gas pipelines
3. Results of full-scale burst test using X100 or X120 line pipes
4. Intrinsic arrestability of X100 or X120 in real pipelines
5. Summary

# Comparison of Gas Transportation Cost




Ref: S. Cornot-Gandolphe, O. Appert, R. Dickel, M-F. Chabrelie, A. Rojey
22nd World Gas Conference, 2003 Tokyo, TF9-C, 02op

# Reduction of transport cost by pipeline



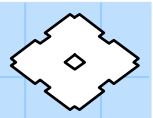

Ref: S. Gower, M. Howard, 22nd World Gas Conference, 2003 Tokyo, TF9-C 03op

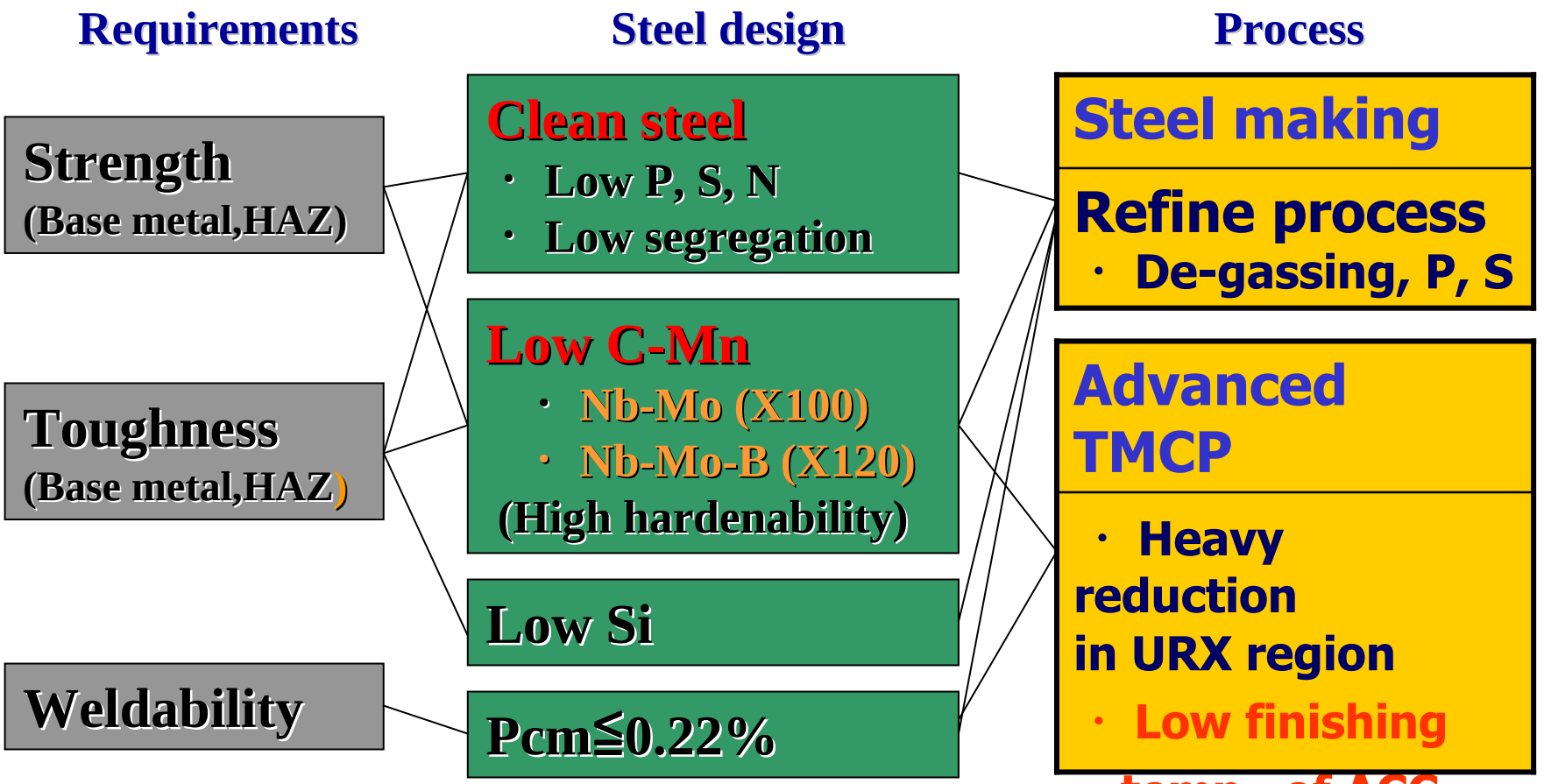
# Large Scale Fracture in High Pressure Gas Pipeline

**Burst Test of gas pipeline : Rich natural gas 11.6MPa, 0.80SMYS of X70, 48inch×18.3mm, 9 Oct. 1982**

**(HLP Committee's 1st Rich Gas Burst Test in BGC)**

# Key factors for manufacturing HSS





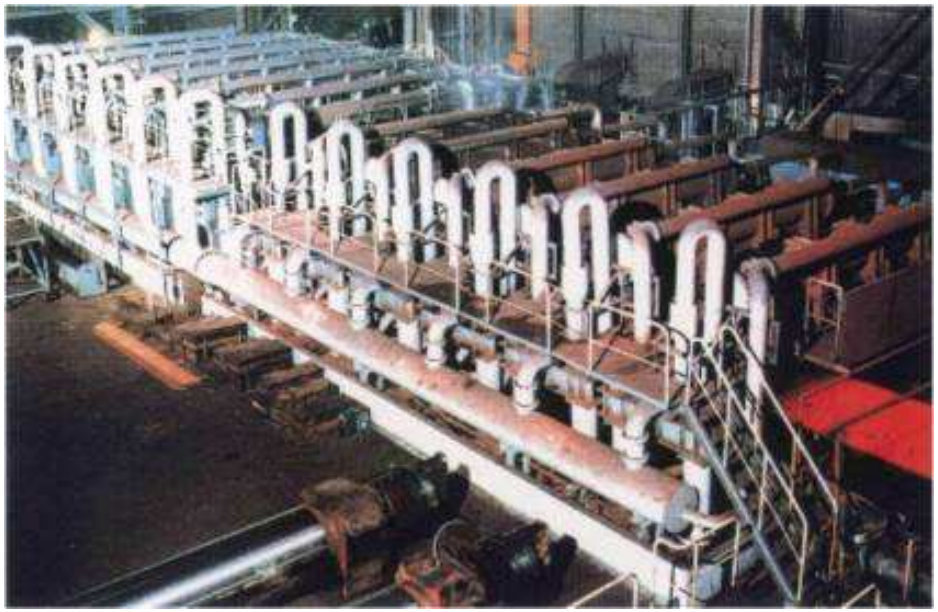

URX : Un-recrystallized
ACC : Accelerated cooling

# Thermo-Mechanical Control Process (TMCP)

- **Hot rolling: re-heating and rolling temperature, reduction are controlled to get optimum micro-structure in hot rolling**

- **Accelerated cooling: cooling speed, cooling start and finishing temperature are controlled to achieve optimum micro-structure**

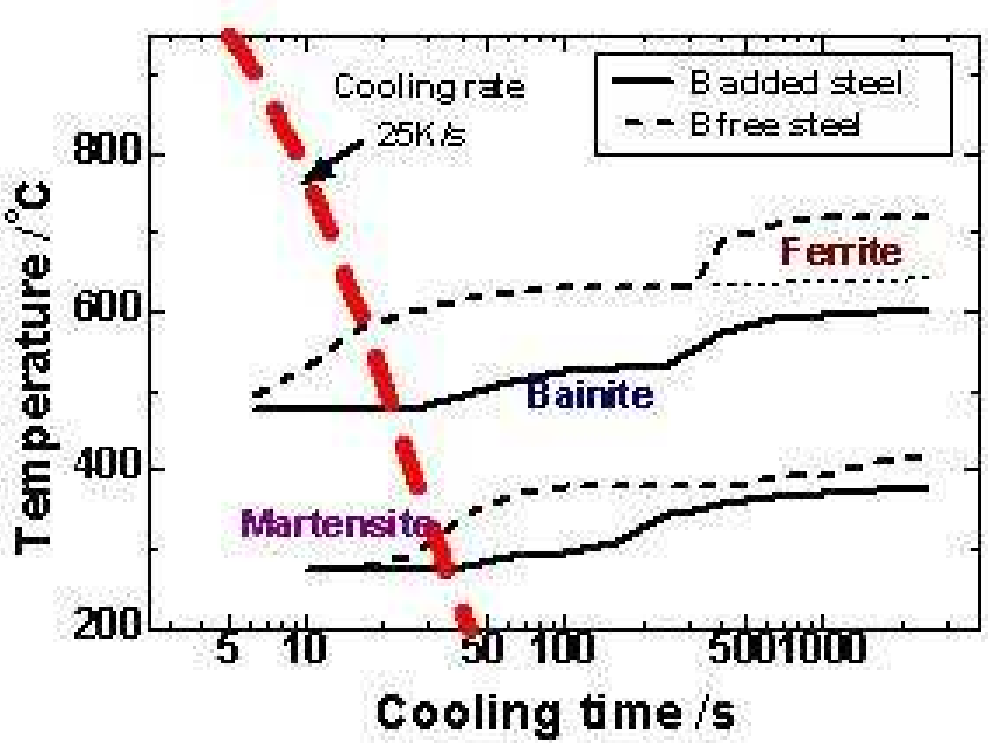
**Finishing Mill**



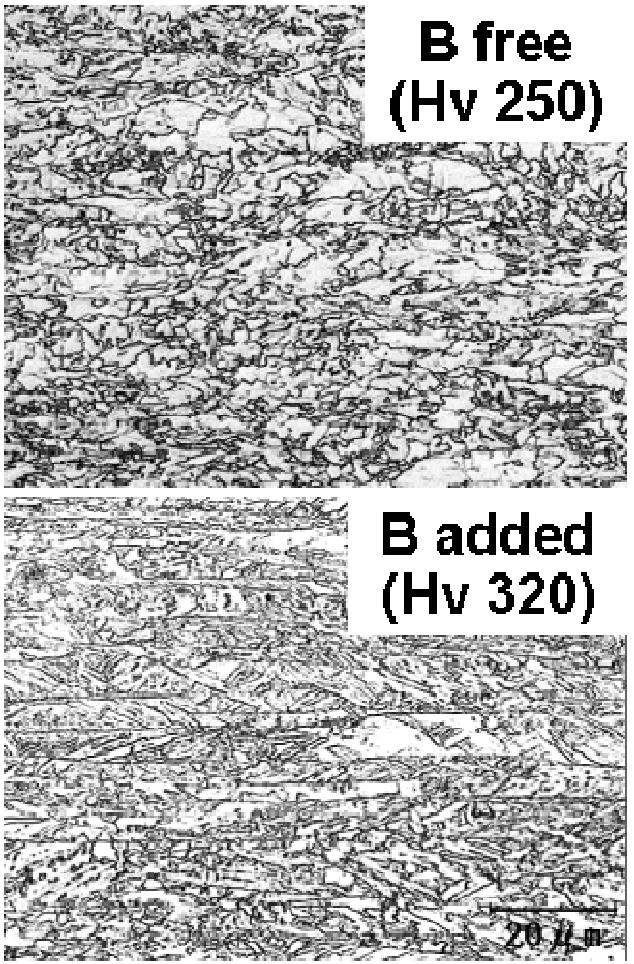
**DAC1 Facility**

# Effect of boron in HSS linepipe

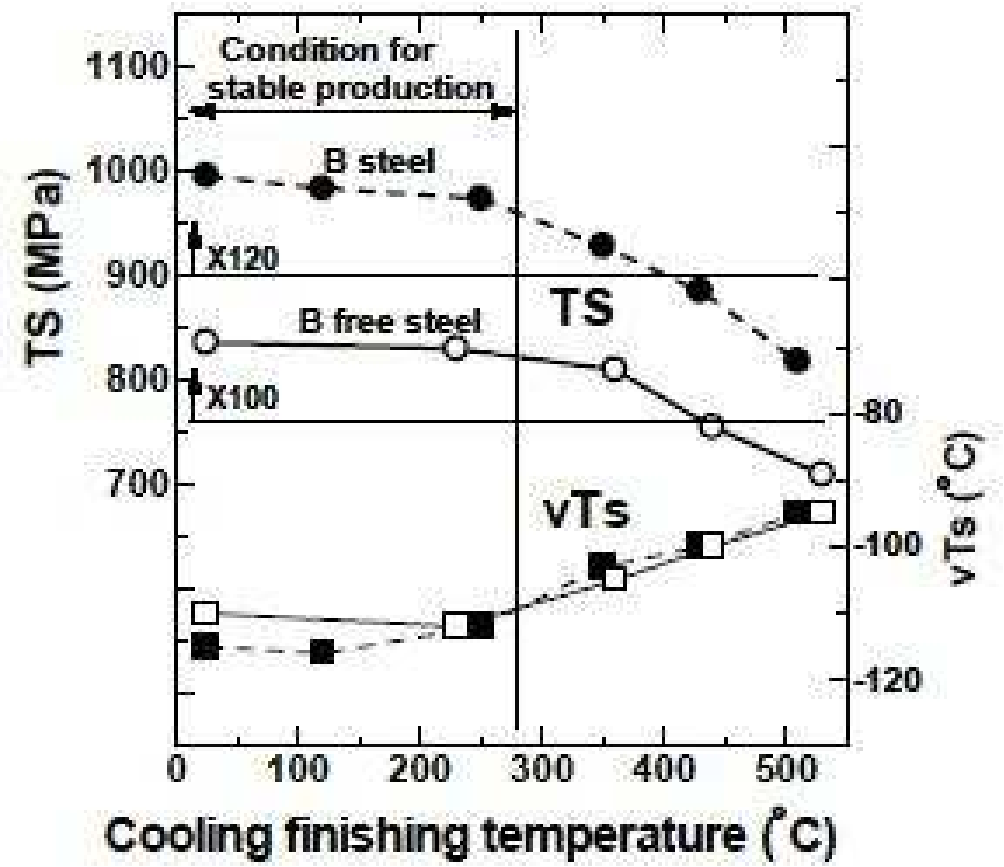
- **Boron enhanced the formation of martensite and lower bainite microstructure in low Pcm steels.**




**Effect of B on CCT diagram after deformation (0.05C-Mn-Ni-Cu-Cr-Mo-Nb-V-Ti, Pcm 0.2%)**



# Control of HSS properties by TMCP




- **Both strength and toughness improve and become more stable, by lowering the CFT below about 300°C**

- **Tensile strength of the boron free and the boron bearing steel with low CFT satisfied the target values of X100 and X120.**

**Effect of cooling stop temperature on TS and vTs**
- **0.06C-Mn-Cu-Ni-Cr-Mo-Nb-V-Ti steel (for X100 19mmt)**
- **0.05C-Mn-Cu-Ni-Cr-Mo-Nb-V-T-B steel (for X120 16mmt)**

# Pipe forming of HSS linepipe

- **Size of prototype pipe**
  - ·X100 : 0.75”(19mm) WT – 36”(914mm) OD
  - ·X120 : 0.63”(16mm) WT – 36”(914mm) OD

U press

O press

- **UOE forming**
- **SAW welding**
  **Inside :**
  **3-electrodes**
  **Outside:**
  **4-electrodes**

**Minimizing heat input for HAZ toughness**

# Production results of HSS linepipe

## Tensile Properties of X100 and X120 linepipe

| Grade | X100 | | | X120 | | |
|---|---|---|---|---|---|---|
| Tensile property | YS | TS | Y/T ratio | YS | TS | Y/T ratio |
| Round bar speci. | 803MPa | 863MPa | 0.93 | 993MPa | 1020MPa | 0.97 |
| API strip speci. | 686MPa | 842MPa | 0.81 | 885MPa | 1029MPa | 0.86 |
| Burst stress | | 856MPa | | | 1056MPa | |
| | *>690MPa* | *>760MPa* | | *>830MPa* | *>915MPa* | |

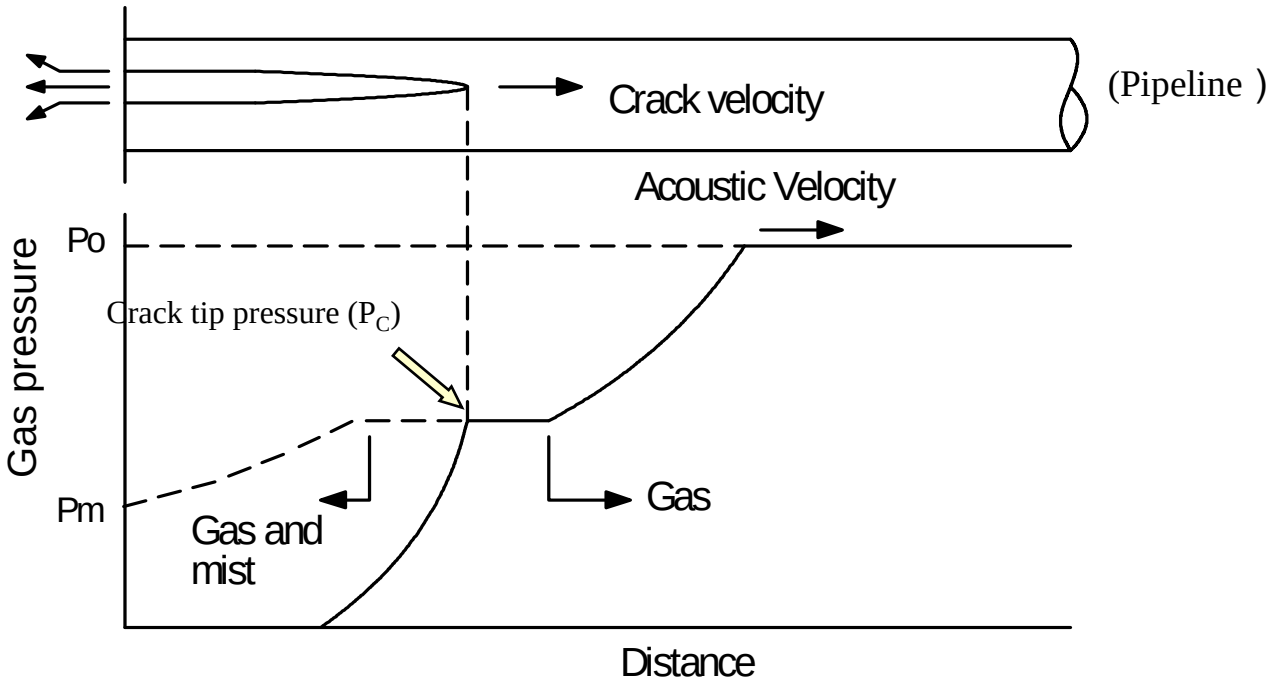
## Toughness of X100 and X120 linepipe

| X100 | | | | X120 | | | |
|---|---|---|---|---|---|---|---|
| Charpy impact property (at -10℃) | | | DWTT | Charpy impact property (at -30℃) | | | DWTT |
| BaseMetal | Weld | HAZ | SA-10℃ | BaseMetal | Weld | HAZ | SA-20℃ |
| 261J | 132J | 154J | 97% | 262J | 88J | 174J | 88% |

# Propagating shear fracture in gas pipeline

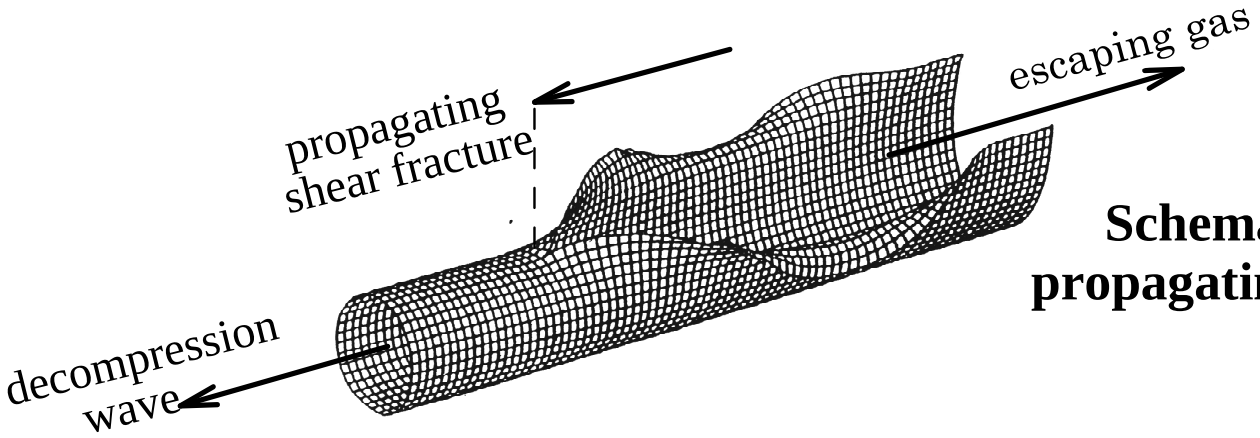
## General observation in full scale gas burst test

- Slower gas decompression velocity during fracture leads long crack propagation.
- Higher-strength pipes tend to have long fracture due to high crack propagation velocity
- Higher design factor increases crack propagation length.
- Lower toughness pipes hardly arrest crack propagation.




Gas pressure distribution during propagating shear fracture

# Concept of two curve method

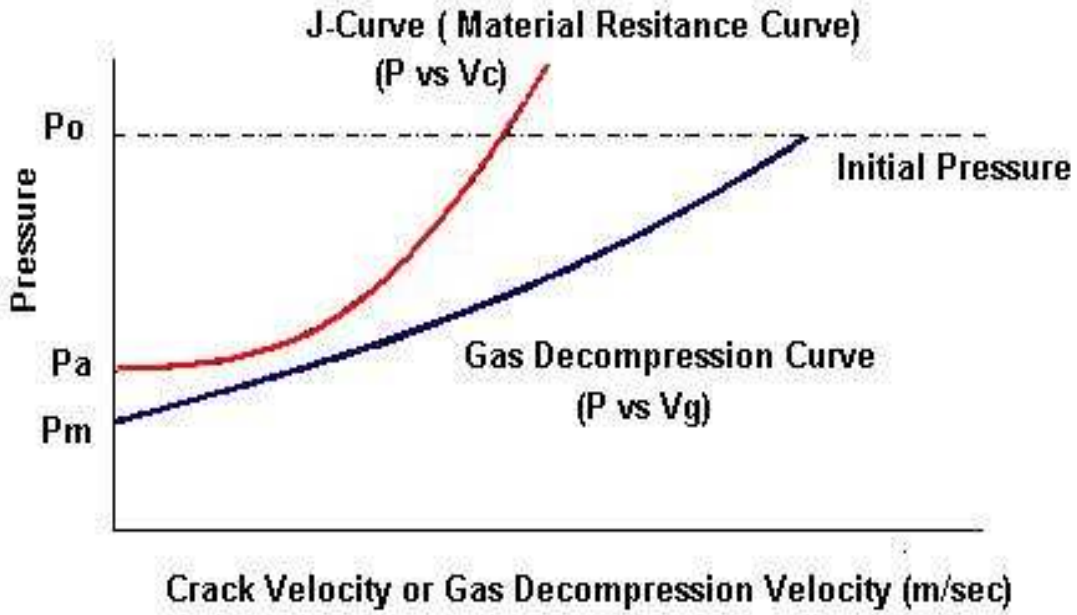



**Schematic illustration of propagating shear fracture in pipelines**

**"J-curve" (crack velocity curve) relationship between the pressure at crack tip and the crack velocity**

$$V_c = \alpha \times \frac{\sigma_{flow}}{\sqrt{D_p / A_p}} \times \left( \frac{P}{P_a} - 1 \right)^{\beta}$$

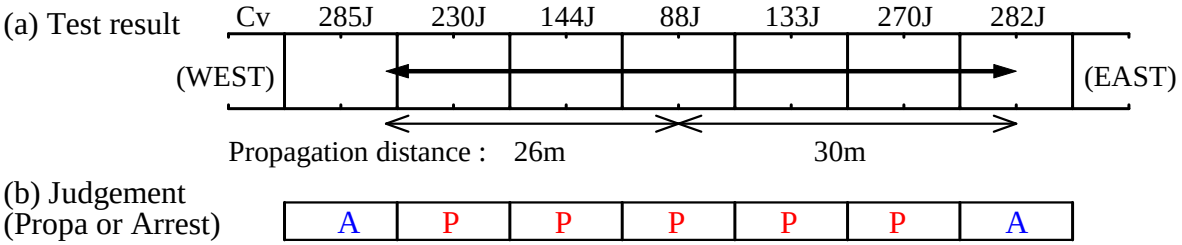
**"Gas decompression curve" relationship between the pressure and the gas decompression velocity.**



# Different concept of crack arrest energy

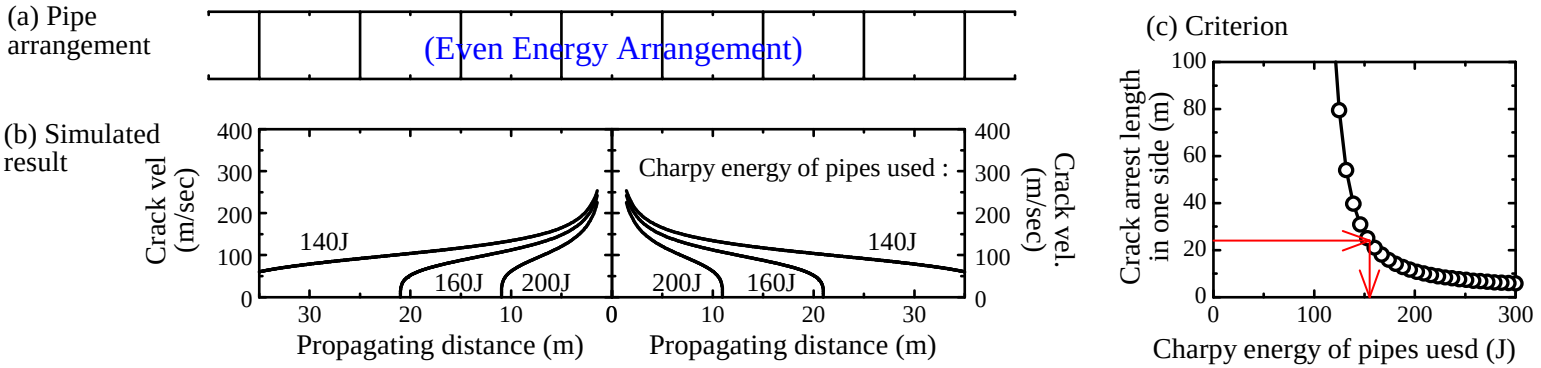
| Item | BMI Two Curve Method<br>Present ISO/EPRG Recommendation | HLP simulation method |
|---|---|---|
| 1. Test Procedure | Increment Energy Arrangement | Even Energy Arrangement or Increment Arrangement |
| 2. Judgment | Go/No-go Judgment | Crack Arrest Length |
| 3. Criterion | Arrest Pipe Energy | 24m Each Side Arrest Energy |

## *Traditional BMI Two Curve Method*




<CSM/SNAM/ILVA-X80 Test>
X80, 56"OD, 26mmWT, +15℃
16.1MPa (0.80SMYS) , "Air"

## *HLP Method*

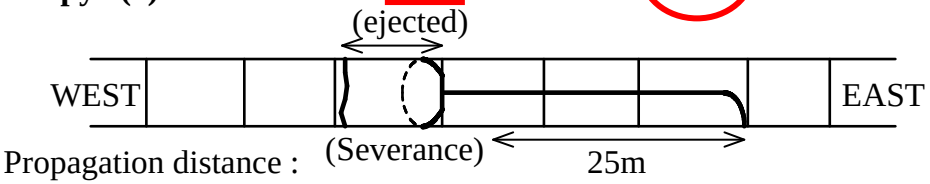


# Review of full scale burst test of X100 linepipe -1

**OD:56”**
**WT:19.1mm**

**(a) 1st ECSC Test results**

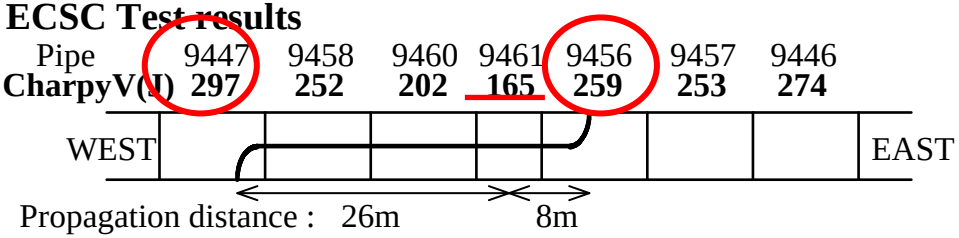
| Pipe | 6020 | 6083 | 6129 | 6113 | 6058 | 6157 | 6061 |
|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **271** | **245** | **200** | **151** | **170** | **263** | **284** |




**OD:36”**
**WT:16mm**

**(b) 2nd ECSC Test results**

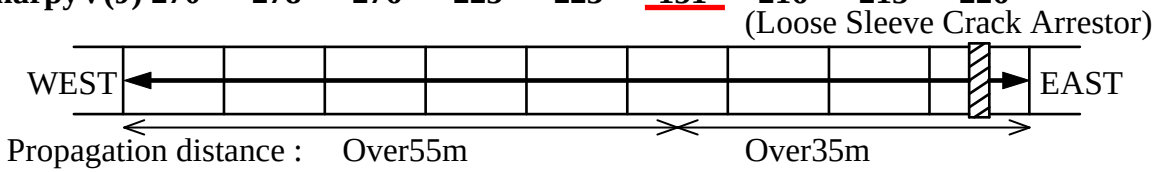
| Pipe | 9447 | 9458 | 9460 | 9461 | 9456 | 9457 | 9446 |
|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **297** | **252** | **202** | **165** | **259** | **253** | **274** |




**OD:36”**
**WT:16mm**

**(c) ExxonMobil X120 Test results**

| Pipe | 5W | 4W | 3W | 2W | 1W | Initiator | 1E | 2E | 3E |
|---|---|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **270** | **278** | **276** | **225** | **223** | **151** | **216** | **215** | **226** |




Arrest energy

(Propagate)

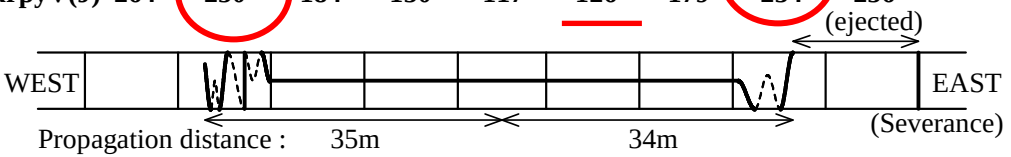
# Review of full scale burst test of X100 linepipe -2

○ *Arrest energy*

**(a) Advantica's JIP No.1 Test results**

| Pipe | 4W | 3W | 2W | 1W | Initiator | 1E | 2E | 3E | 4E |
|---|---|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **264** | **250** | **184** | **150** | **117** | **126** | **179** | **254** | **256** |

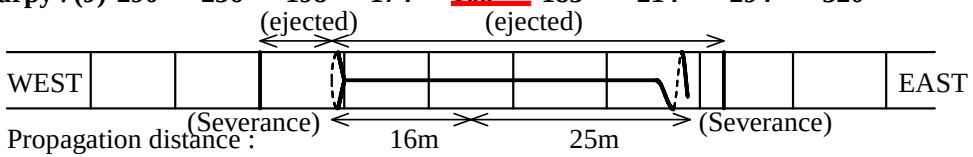
**OD:36”**
**WT:13mm**




**(b) Advantica's JIP No.2 Test results**

| Pipe | 4W | 3W | 2W | 1W | Initiator | 1E | 2E | 3E | 4E |
|---|---|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **290** | **256** | **198** | **174** | **168** | **185** | **214** | **294** | **320** |

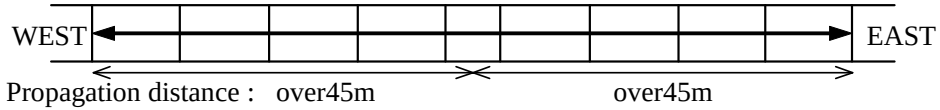
**OD:36”**
**WT:15mm**




**(c) 1st DemoPipe Test results**

| Pipe | 8808 | 8795 | 8797 | 8786 | 8781 | 8783 | 8780 | 8799 | 8776 |
|---|---|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **291** | **249** | **237** | **215** | **193** | **228** | **223** | **258** | **355** |

**OD:36”**
**WT:16mm**

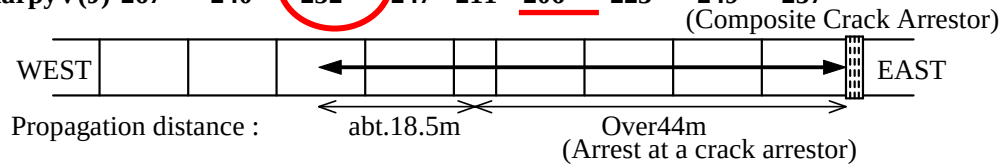



**(Propagate)**

**(d) 2nd DemoPipe Test results**

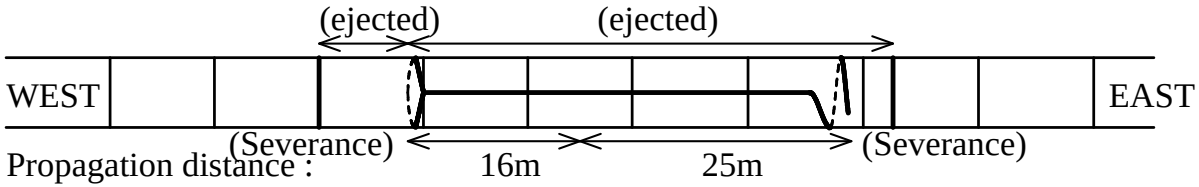
| Pipe | 8824 | 8826 | 8834 | 8831 | 8837 | 8835 | 8839 | 8836 | 8851 |
|---|---|---|---|---|---|---|---|---|---|
| **CharpyV(J)** | **267** | **240** | **252** | **247** | **211** | **206** | **223** | **249** | **257** |

**OD:36”**
**WT:20mm**



# Effect of energy gradient on arrest length

## (a) Test result (Advantice' JIP No.2 Test)



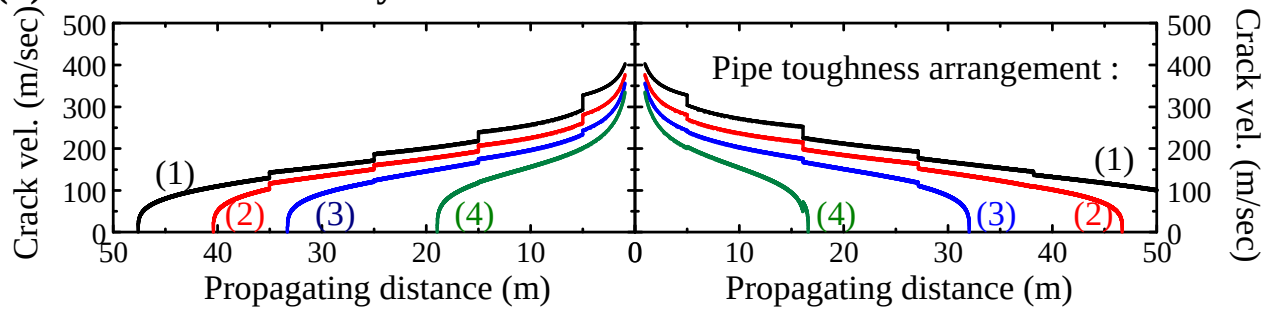

## (b) Pipe data

| Pipe | 4W | 3W | 2W | 1W | Initiator | 1E | 2E | 3E | 4E |
|---|---|---|---|---|---|---|---|---|---|
| Length(m) | 10.02 | 10.02 | 10.00 | 10.00 | 10.01 | 11.08 | 11.07 | 11.03 | 11.04 |
| YS(MPa) | 836 | 821 | 844 | 836 | 834 | 876 | 839 | 846 | 782 |
| TS(MPa) | 850 | 832 | 856 | 849 | 853 | 919 | 897 | 887 | 856 |

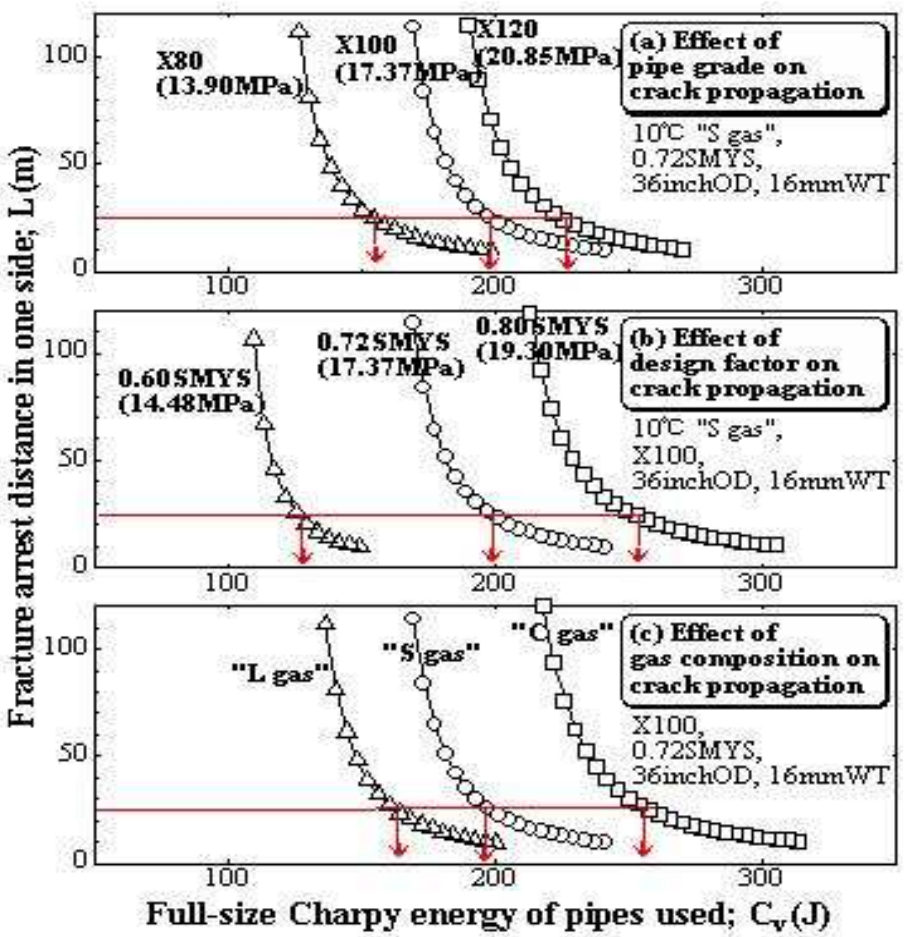
## (c) Pipe toughness arrangement (CharpyV(J))

| Pipe | 4W | 3W | 2W | 1W | Initiator | 1E | 2E | 3E | 4E | Gradient |
|---|---|---|---|---|---|---|---|---|---|---|
| Arrangement (1) | 350 | 300 | 250 | 200 | 150 | 200 | 250 | 300 | 350 | +50J/Pipe |
| Arrangement (2) | 320 | 285 | 250 | 215 | 180 | 215 | 250 | 285 | 320 | +35J/Pipe |
| Arrangement (3) | 290 | 270 | 250 | 230 | 210 | 230 | 250 | 270 | 290 | +20J/Pipe |
| Arrangement (4) | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 0J/Pipe |

## (d) Simulated results by HLP method



# Effect of operating condition on arrest length




- Thin wall high strength pipe requires higher energy
- High design factor (high operation pressure ) requires higher energy
- Dense gas requires higher energy

| Gas | $CH_4$ | $C_2H_6$ | $C_3H_8$ | $iC_4H_{10}$ | $nC_4H_{10}$ | $iC_5H_{12}$ | $nC_5H_{12}$ | $nC_6H_{14}$ | $>=nC_7H_{16}$ | $N_2$ | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| “L gas” | 96.00 | 3.80 | 0.15 | 0.02 | 0.03 | ----- | ----- | ----- | ----- | ----- | ----- |
| “S gas” | 92.00 | 4.00 | 2.00 | 0.30 | 0.50 | 0.100 | 0.050 | 0.050 | ----- | 0.50 | 0.50 |
| “C gas” | 89.57 | 4.70 | 3.47 | 0.24 | 0.56 | 0.106 | 0.075 | 0.033 | 0.026 | 0.50 | 0.72 |

# Summary

- API grade X100 and X120 linepipes for gas transmission pipeline have been successfully developed.
- TMCP with low cooling finishing temperature is key to achieve good balance of strength and toughness together with optimum chemistry
- Fracture arrestability of X100 or X120 was analyzed by HLP method based on reported full scale burst test
- Energy gradient arrangement in full scale test has the effect on fracture length
- Developed HSS has high possibility to arrest fracture in specific operating condition