Low-temperature CO_2 removal from natural gas

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Presentation outline

- Part 1: Walkthrough of low-temperature CO_2 removal process from natural gas with high CO_2 content (D. Berstad)
  - Introduction
  - Process flow diagram
  - Boundary conditions
- Part 2: Key performance parameters (S. Roussanaly)
  - Energy Key Performance Indices (KPI)
  - Preliminary volume and weight estimates

Background

- Low-temperature CO_2 removal from hydrocarbons is not a new technology
- The Ryan/Holmes process was patented in the early 1980s
- In use for EOR on sites in the United States. Examples:
  - Dry Trail Gas Plant, Oklahoma (1996)
  - Chevron Buckeye CO_2 plant, New Mexico (1998)
- Extractive distillation of hydrocarbons and CO_2. Number of columns and sequence depending on product specifications
  - CO_2
  - Natural gas
  - NGL
  - etc.

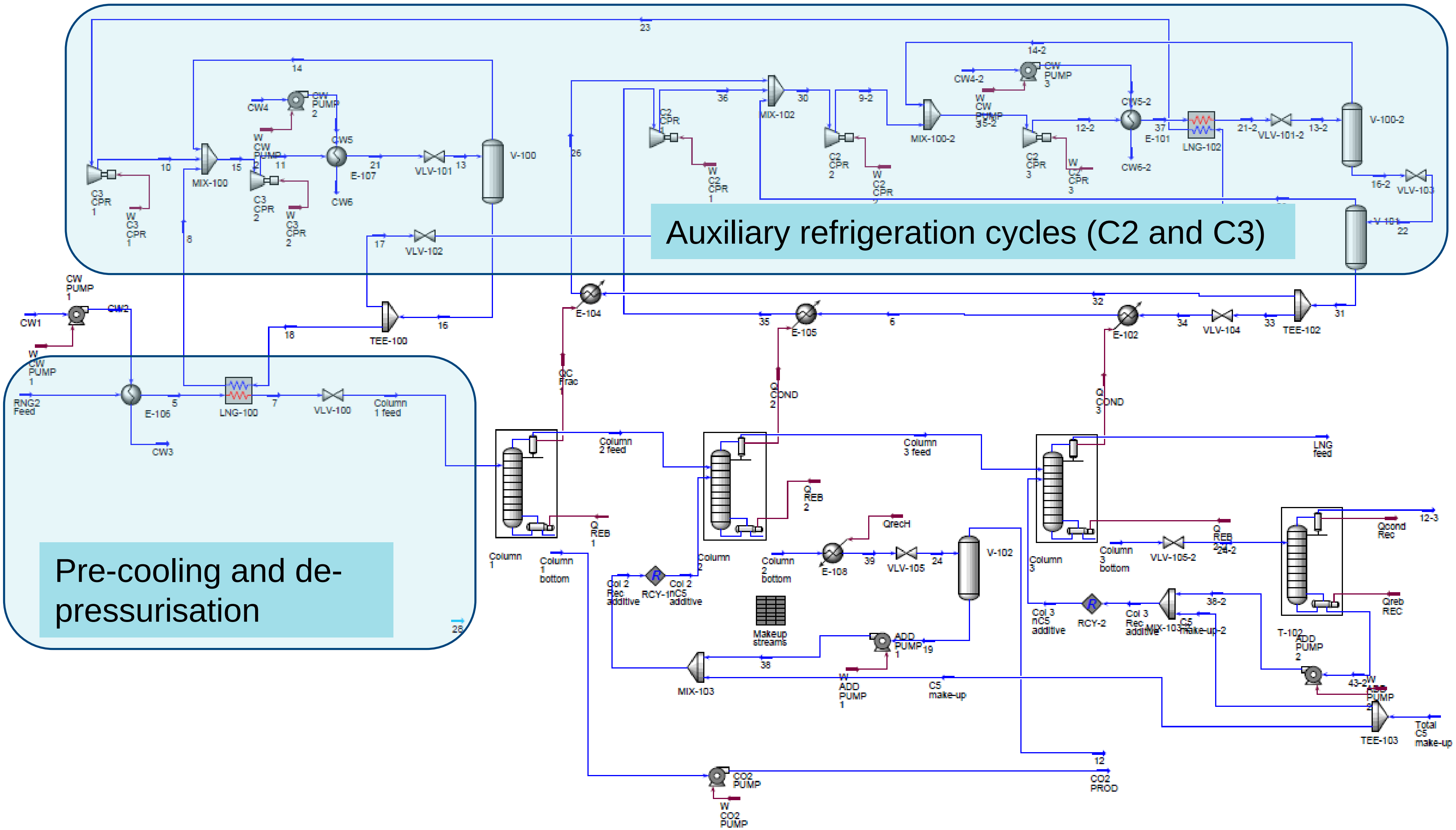
Background

- Low-temperature CO_2 removal from natural gas usually requires regenerative circulation of heavier hydrocarbons in distillation columns
  - CO_2 freezing point depression allowing low-temperature operation (< -80°C)
  - Breaking azeotropes to get higher product purity (for instance for ethane/CO_2 fractionation)
- From CCS experience, low-temperature CO_2 separation/capture processes benefit from high initial CO_2 concentration
- Research need: estimate energy consumption, size and weight for Ryan/Holmes-type of CO_2 removal process for natural gas and benchmarking with baseline technologies

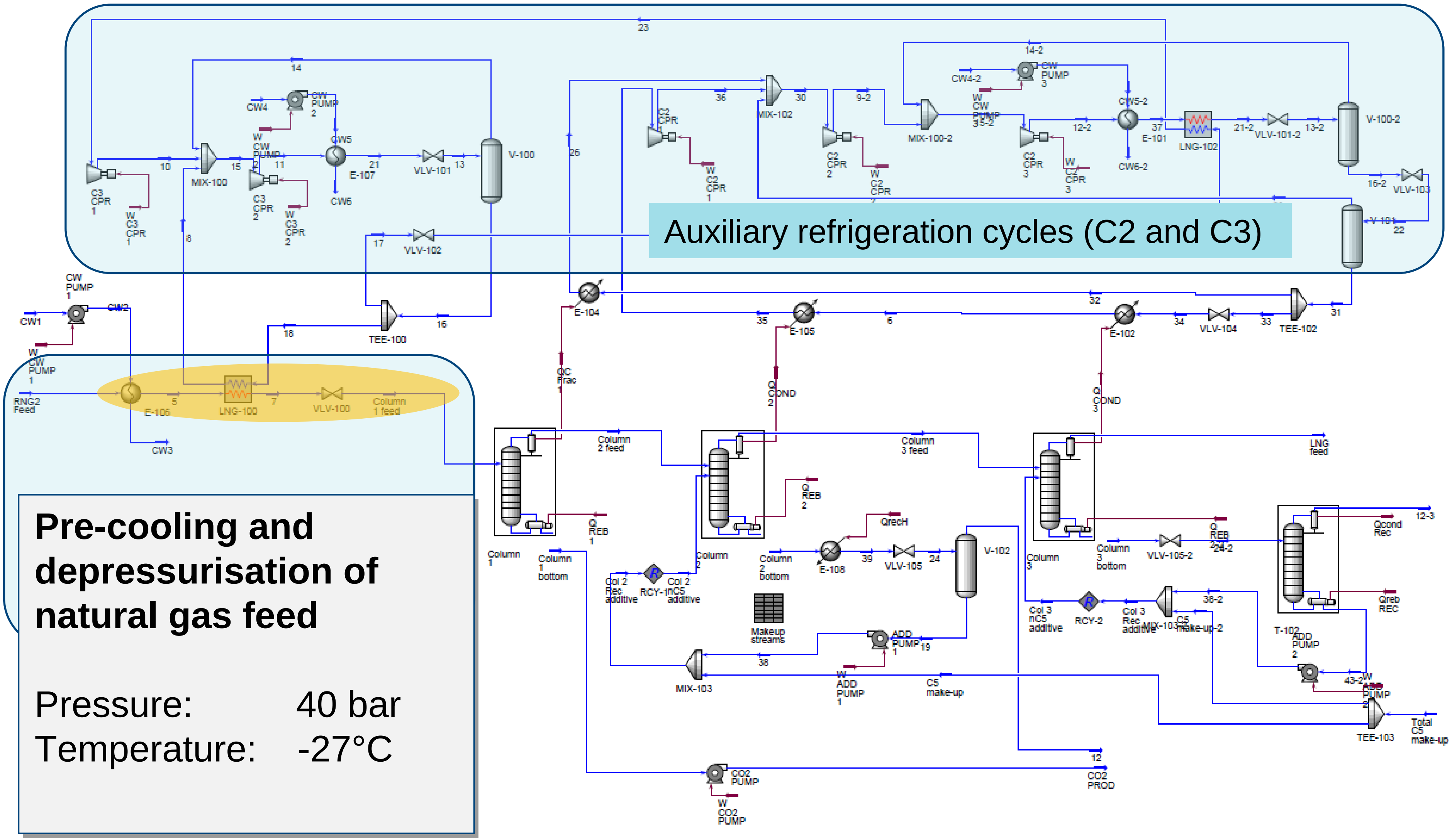
Boundary conditions

		Natural gas feed	CO_2 product	LNG feed	Pipeline gas
Temperature	°C	**40**			
Pressure	bar	**70**	**110**		
Flowrate	Nm^3/hr	**590**			
	MSm^3/day	**15**			
Composition					
C1	vol%	**39.3**			
C2	vol%	**3.5**			
C3	vol%	**2.4**			
C4	vol%	**1.8**			
C5	vol%	**1.2**			
C6+	vol%	**0.2**			
CO_2	vol%	**50**	**70–95**	**50 ppm**	**2.5**
Sulphur	vol%	**1**			
Organic suplhides	vol%	**0.02**			
Nitrogen	vol%	**0.5**		**< 1**	
BTEX	vol%	**0.1**			

Process layout (HYSYS PFD)



Process layout (HYSYS PFD)

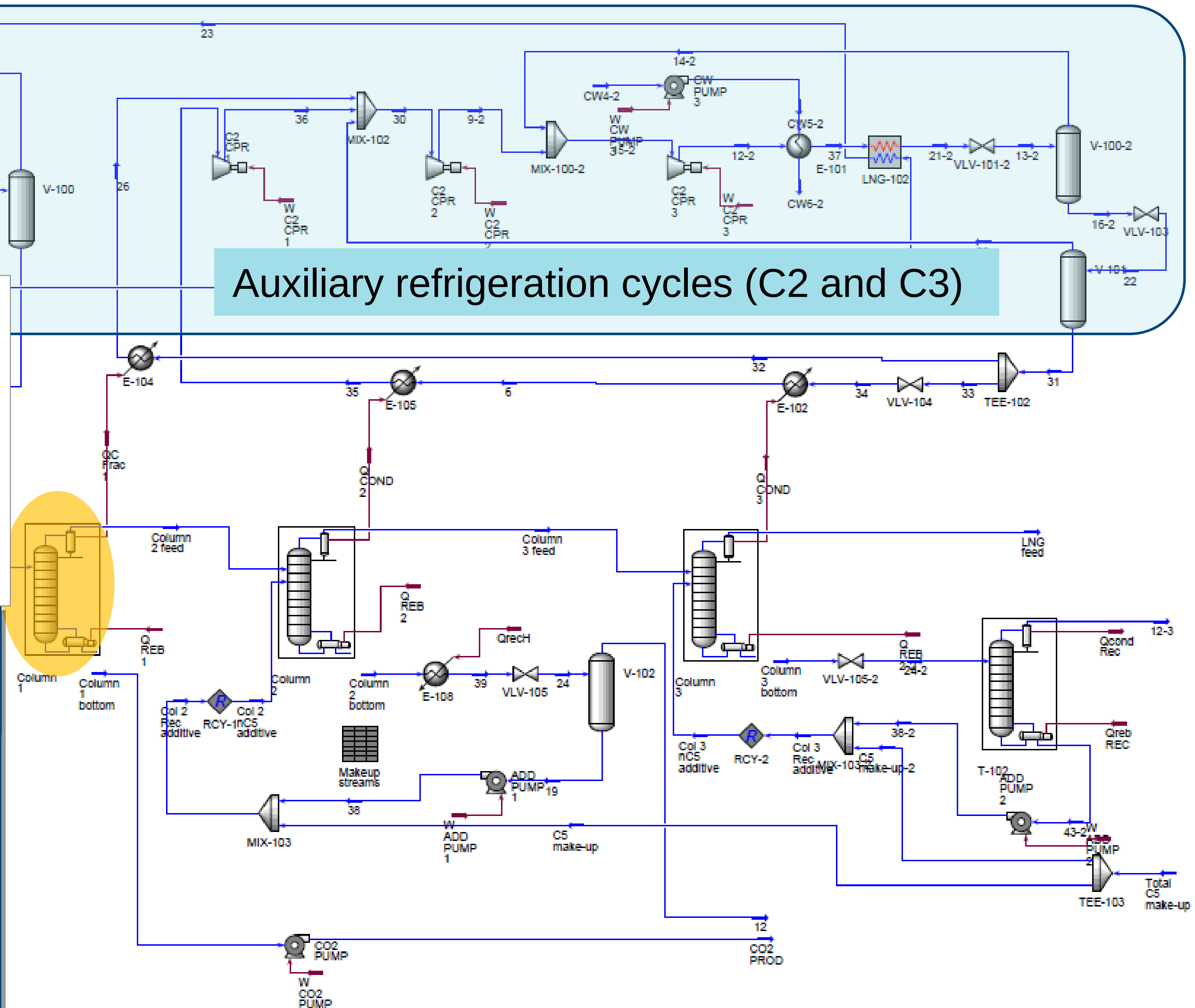


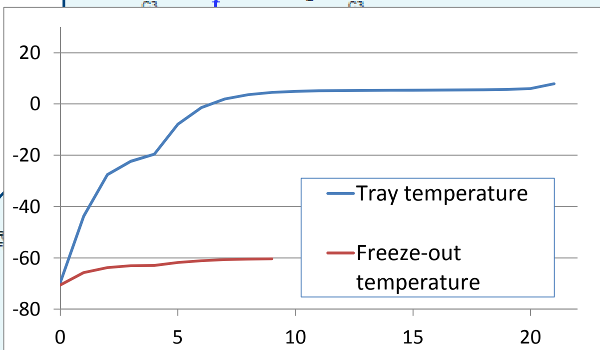
Pre-cooling and depressurisation of natural gas feed

Pressure: 40 bar

Temperature: -27°C

Process layout (HYSYS PFD)



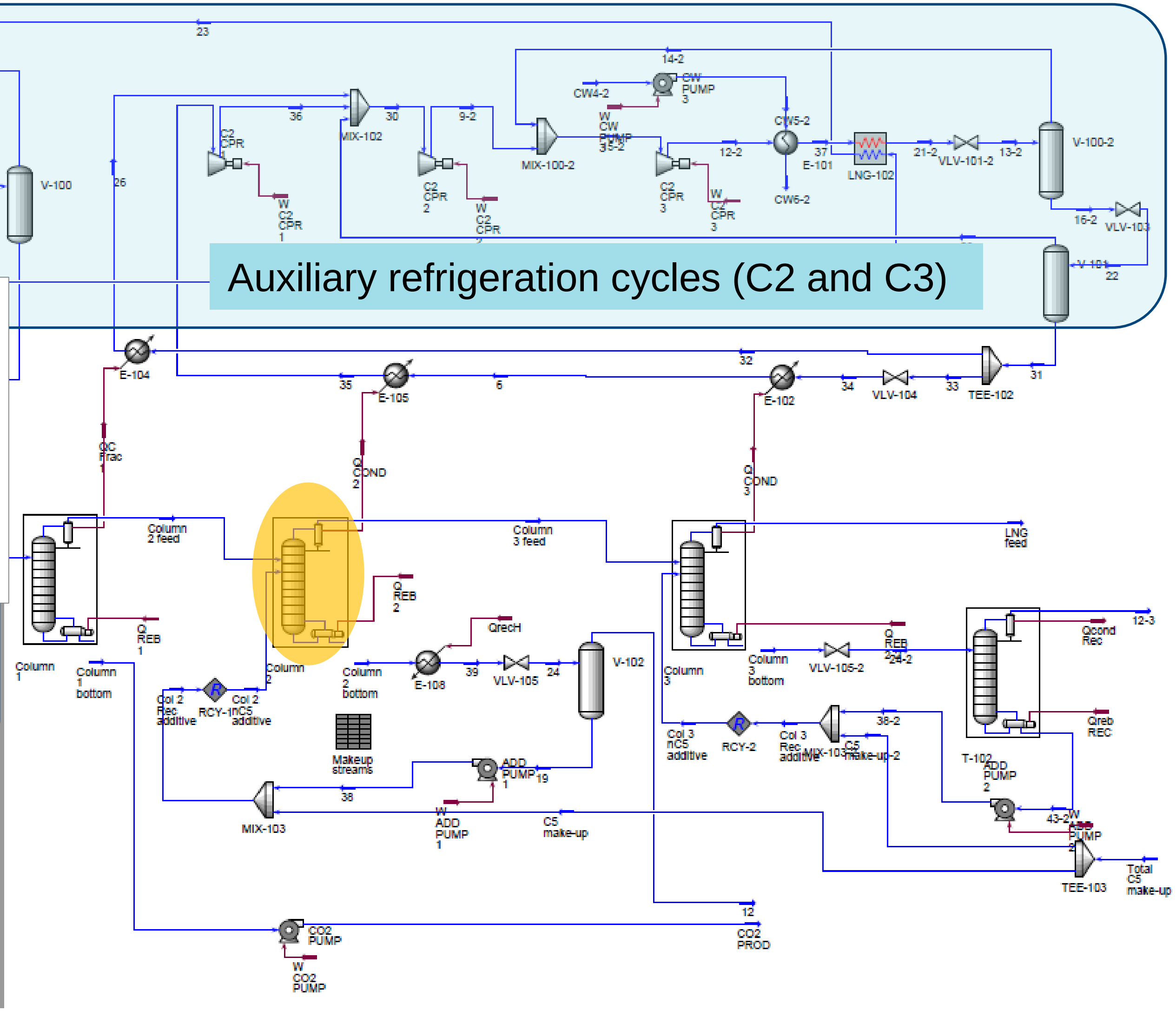


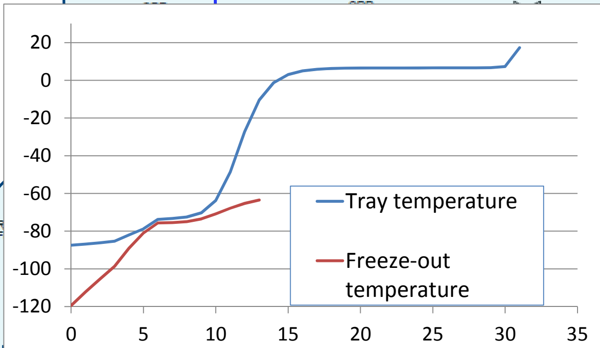
Bulk removal column

Condenser T:	-69.8°C
Reboiler T:	7.9°C
Reflux ratio:	2.0

Top product		Bottom product	
C1:	87.3%	C2:	4.5%
C2:	2.2%	C3:	4.4%
CO2:	9.3%	C4+:	5.8%
N2:	1.1%	CO2:	83.3%
		H2S:	1.8%

Process layout (HYSYS PFD)



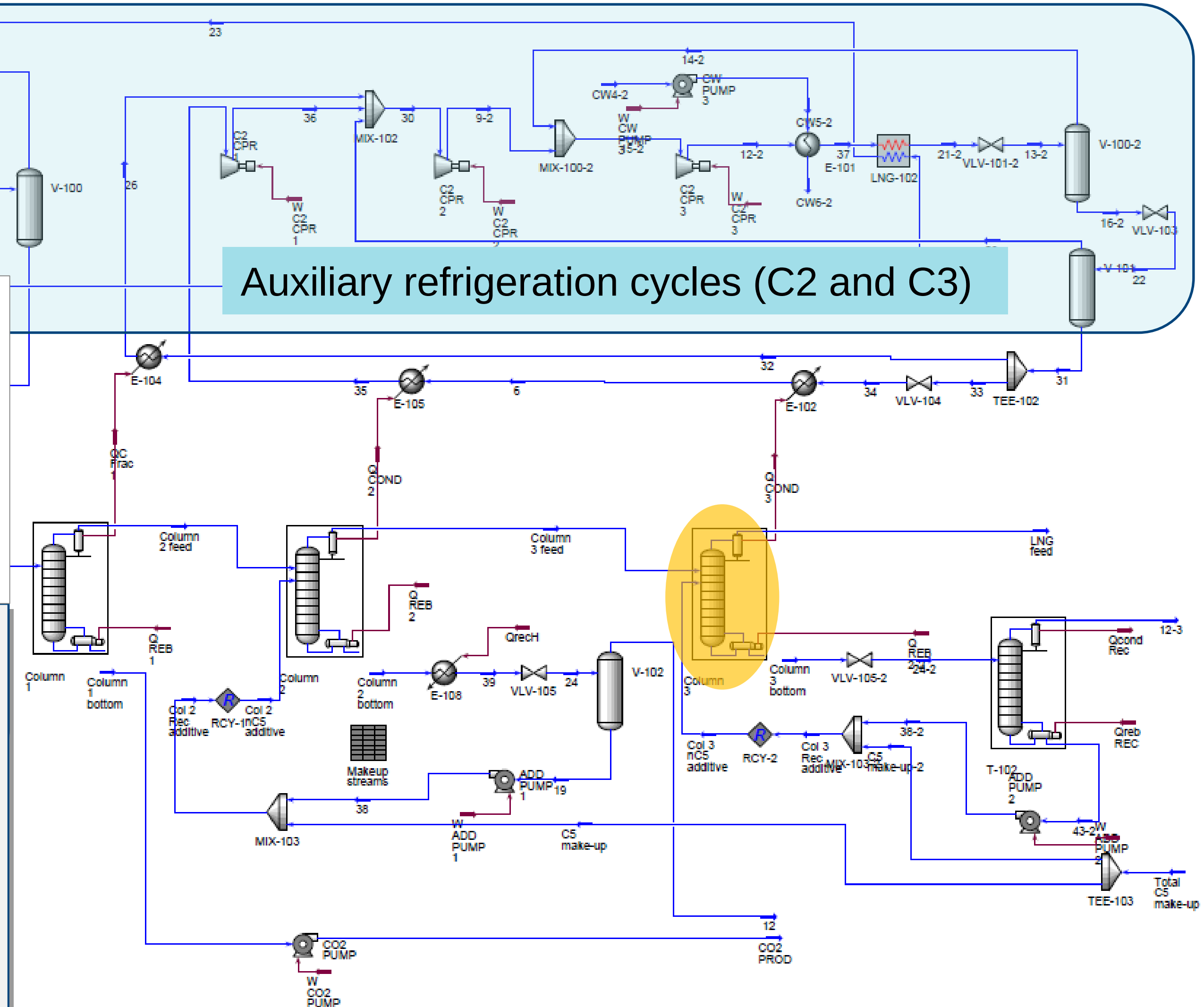


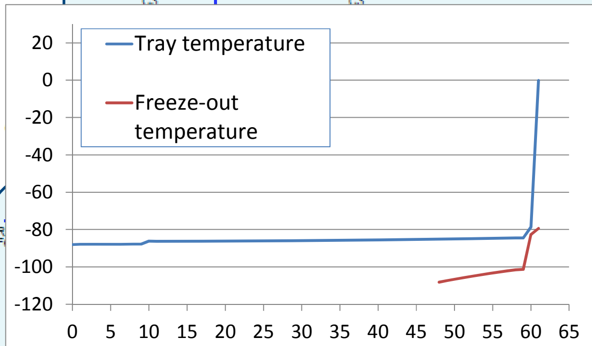
2nd column

Condenser T:	-87.4°C
Reboiler T:	17.3°C
Reflux ratio:	1.65

Top product		**Bottom product**	
C1:	98.2%	C2:	15.5%
C2:	0.01%	C3-4:	0.08%
CO_2:	0.6%	C5:	29.3%
N_2:	1.2%	CO_2:	54.8%
		H_2S:	0.36%

Process layout (HYSYS PFD)



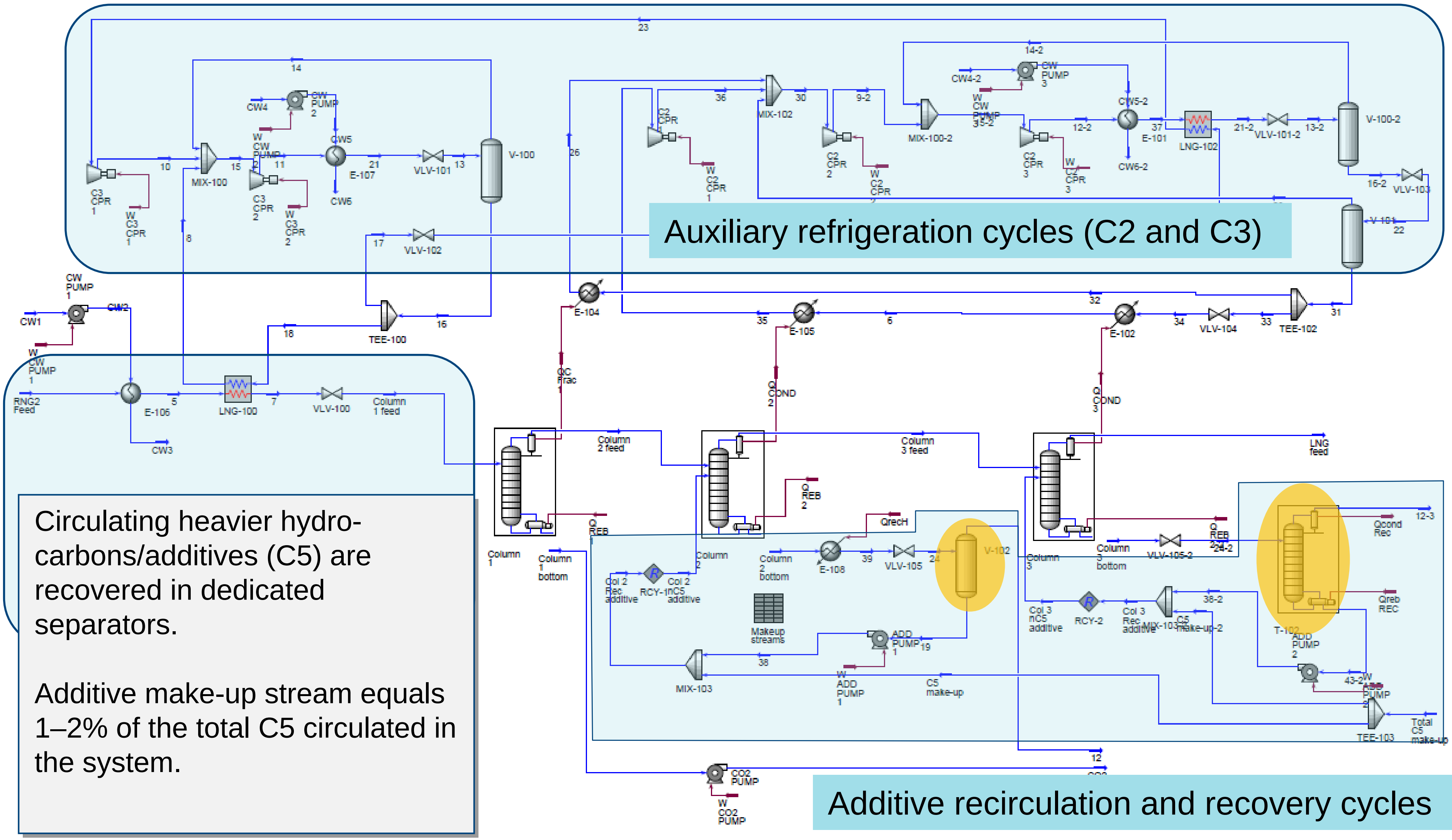


3rd column

Condenser T:	-88.0°C
Reboiler T:	-0.1°C
Reflux ratio:	1.11

Top product		**Bottom product**	
C1:	98.7%	C1:	20.1%
N2:	1.3%	C2	0.19%
CO2:	50ppm	C5:	71.7%
		CO2:	7.8%
		H2S:	68ppm

Process layout (HYSYS PFD)



Circulating heavier hydro-carbons/additives (C5) are recovered in dedicated separators.

Additive make-up stream equals 1–2% of the total C5 circulated in the system.

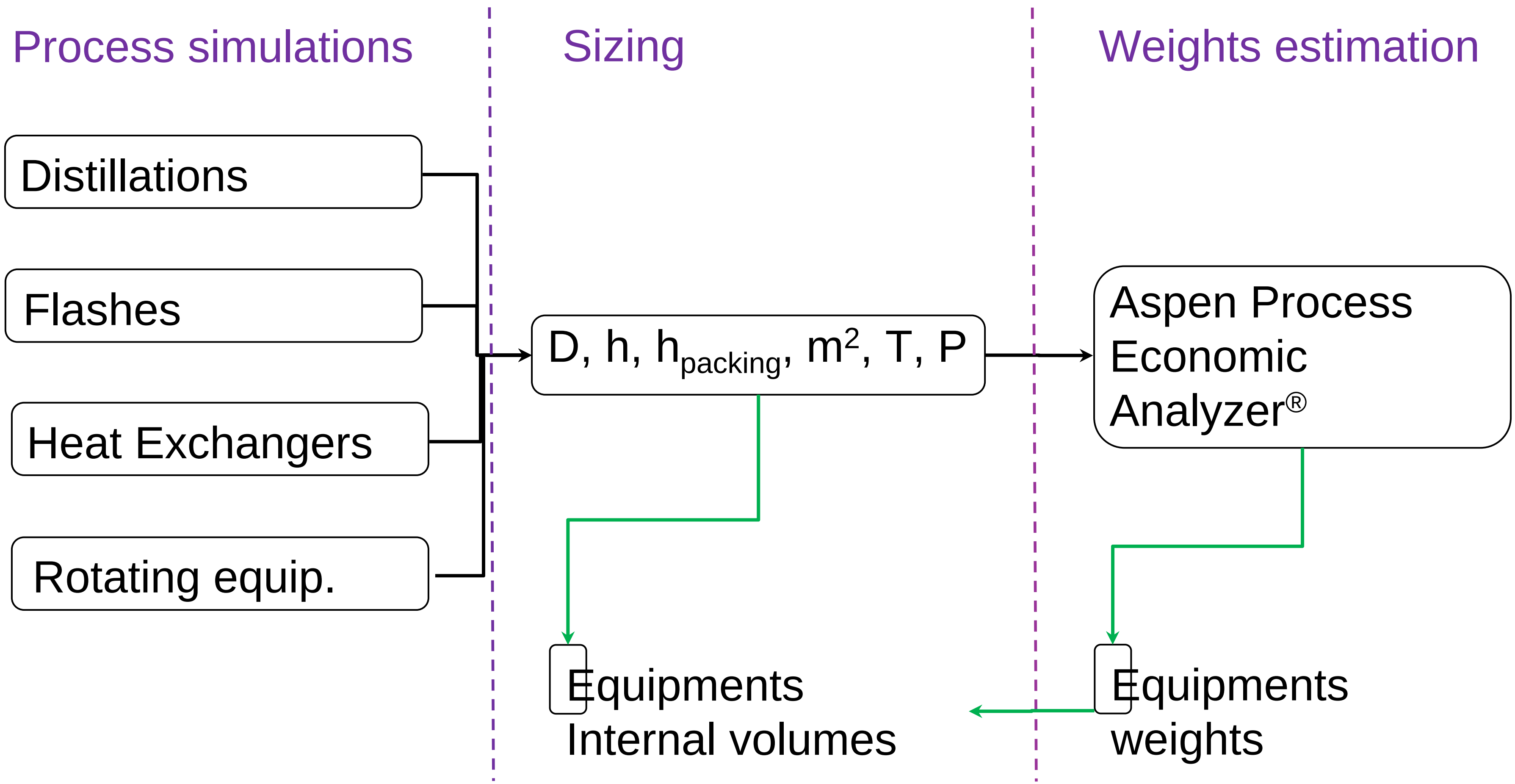
Attainment of product specifications for LNG-quality NG (most challenging specifications)

		Unit	Spec.	Current results	Comment
LNG feed	Inert concentration	mol-%	< 1	1.27	All nitrogen in raw natural gas stream inevitably follows methane due to lower boiling point. May be flashed off in the LNG train.
	CO_2 concentration	ppmv	50	50	Obtained in simulation model with 60 theoretical stages in 3rd distillation column.
	Sulphur concentration	mg/Nm^3	≤ 5	0	
CO_2 product	CO_2 concentration	mol-%	70–95	83.3	Higher concentration will be obtained if CO_2 and heavier hydrocarbons are further separated.
	CO_2 pressure	bar	110	110	Liquid pumping from 40 to 110 bar.

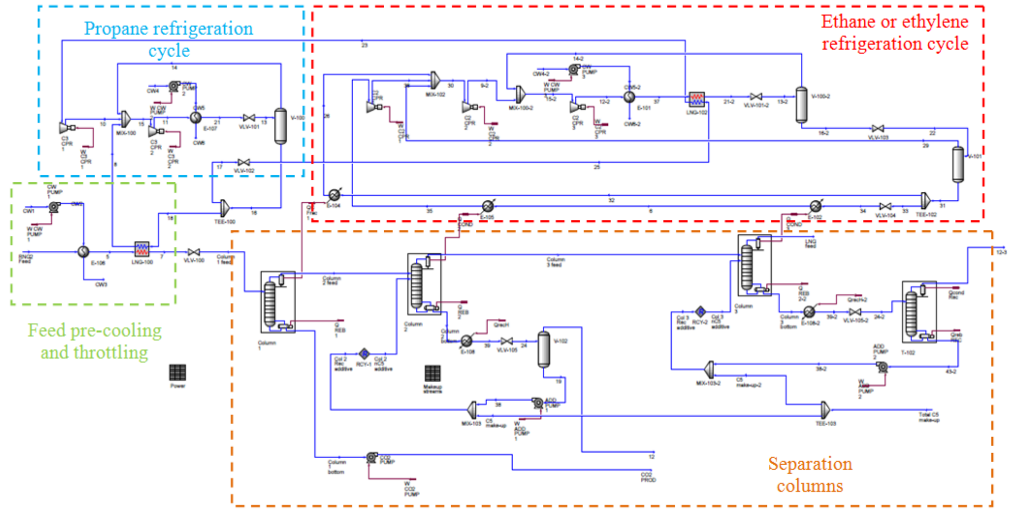
Energetic KPIs

	CO_2 Recovery %	Methane Slip %	Thermal efficiency %	System efficiency %
Pipe Spec	88	0.1	99	97
LNG Spec	92	5.9	95	93

KPIs: Volume and weight



KPIs: Volume and weight



LNG Spec (50 ppm CO_2)

- **Volume**
  - Primarily due to flashes
  - Secondarily due to condensers/reboilers
- **Heat exchangers area**
  - Mainly due to distillation
  - Mainly located in separation
- **Weight**
  - Primarily due to condensers/reboilers
  - Secondarily due to compressors
  - Equal proportions between separation and refrigeration subsystems

Area	Feed	Sep	C3R	C4R	Global
Internals volume (m^3)	8	326	459	285	1,079
Distillation columns		28%			9%
Condensers/Reboilers		65%			20%
Flashes		6%	82%	72%	56%
Heat exchangers	100%		5%	17%	8%
Rotating equipment		1%	12%	11%	8%
Heat exchangers area (m^2)	789	15,919	2,464	4,826	23,998
Reboilers		48%			32%
Condensers		51%			34%
Heat exchangers	100%	1%	100%	100%	34%
Equipment weights (t)	25	622	326	266	1,238
Distillation columns		25%			12%
Condensers/Reboilers		73%			37%
Flashes			12%	14%	6%
Heat exchangers	95%	1%	19%	38%	15%
Compressors	5%	1%	69%	47%	29%

Concluding remarks

- CO_2 removal to a concentration of 50 ppm for LNG feed seems obtainable, as is 2.5% for pipeline specification
- Three distillation columns have been assumed for LNG case, two columns sufficient for pipeline specification
- Circulation of heavier hydrocarbons/inhibitors is required for freezing point depression. Further verification of freeze-out temperature is needed
- Specific power consumption estimated to about 0.5 MJ/kg CO_2 (LNG spec.)
- Further separation of CO_2/HHC will have benefits:
  - Increased CO_2 concentration
  - Recovery of valuable sales products
  - Eliminate need for inhibitor make-up

Concluding remarks

- Direct comparison with solvent-based technologies is not a straightforward task
  - Low-temperature CO_2 removal is an integral part of an LNG train
    - Methane leaves process at -88°C
    - Dehydration carried out upstream of the CO_2 removal process
- Preliminary sizing and weighting results indicate
  - Competitive weight and size as well as energy requirement

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