Pipeline System Basis of Design

0	18/12/2020	Final Issue	L.Maggiore	E.Bonato	A.Terenzi
A	12/10/2020	Issue for review	L.Maggiore	E.Bonato	A.Terenzi
Rev.	**Date**	**Description**	**Prepared**	**Checked**	**Approved**

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1. INTRODUCTION

1.1 OBJECTIVES OF THE DOCUMENT

Purpose of Basis of Design is to collect data and summary information of the project in order to define the main basic data (fluid composition, feed conditions, plant capacity, turndown, process operating and design cases, product specifications, etc..) for the conceptual design of the CO2 collection pipeline system of the Project.

A Process Design Criteria will be developed to identify the design criteria used for line and equipment sizing.

1.2 DEFINITIONS

The abbreviations when used in this document will have the meanings described here in the following list:

COMPANY/OWNER	VBSA
CONTRACTOR	Saipem S.p.A.
PROJECT	CO2 COLLECTION NETWORK CONCEPTUAL STUDY

1.3 ABBREVIATIONS

API	American Petroleum Institute
ATCI	Actualized Transport Cost Index
CAPEX	Capital Investment Cost
CP	Cathodic Protection
CCS	Carbon Capture and Storage
deg	Degrees
FBE	Fusion Bond Epoxy
FCAW	Flux-cored Arc Welding
HDD	Horizontal Directional Drill
ILI	In-Line Inspection
KM	Kilometre
KP	Kilometre Post
MLBV	Mainline Block Valve
MOP	Maximum Operating Pressure
Mt	Million of tons
NACE	National Association of Corrosion Engineers
NDT	Non-Destructive Testing
NPS	Nominal Pipe Size
OD	Outside Diameter
OPEX	Operating Cost
ROW	Right of Way
SCADA	Supervisory Control and Data Acquisition
SMYS	Specified Minimum Yield Strength
WT	Wall Thickness
3LPE	Three Layer Polyethylene Systems

1.4 APPLICABLE CODES & STANDARDS

- ISO 27913-2016, "Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems (2016)
- DNVGL-RP-F104, "Design and operation of carbon dioxide pipelines" (2019)
- API SPECIFICATION 5L-2018, 46th Edition, "Line Pipe" (2018)

1.5 REFERENCES

1. COMPANY CONTRACT C14474
2. VBSA – ETH Document "Scope for study on CO2 collection infrastructure in Switzerland" (2020)
3. TECHNICAL & COMMERCIAL PROPOSAL No. 20OT4348_T_00, "CO2 COLLECTION NETWORK CONCEPTUAL STUDY" (July 27, 2020)
4. R.H. Perry, D. Green, "Perry's Chemical Engineers' Handbook", 6th Edition, McGraw-Hill New York (1984)
5. Mo Mohitpour et al. "Pipeline Transportation of Carbon Dioxide Containing Impurities" (2012)
6. http://www.worldclimate.com
7. https://www.geo.admin.ch/it/home.html

1.6 UNITS OF MEASUREMENT

The units of measurement used for the project will be in METRIC units except where otherwise stated.

2. PROJECT DESCRIPTION

In the context of negative emissions and decarbonizing industry, carbon capture and storage (CCS) is being discussed as an option for Switzerland. The search for domestic storage sites in ongoing, in the meantime, there could be a possibility of collecting Swiss CO2 and sending it to storage sites under the North Sea, that are planned to open by end of 2024 (Northern Lights project by Equinor, Shell, Total).

In Switzerland, KVA Linth is currently performing a feasibility study for a capture plant with a potential provider, other emitters are also exploring cost and feasibility.

Saipem has been awarded for the feasibility and cost estimate of building a “collection network” (similar to a distribution grid for gas) to connect to Switzerland’s largest CO2 emitters on the one hand and to transmission pipelines on the other hand by 2030.

The study should give a first indication of cost, according to a Class 5 estimate (see Ref. [2]).

Switzerland has currently 32 large emitters, defined as point sources that emit over 100,000 tons/y of CO2 (see Figure 2.1). Together, these 32 large emitters emit about 7 Mt of CO2 per year.

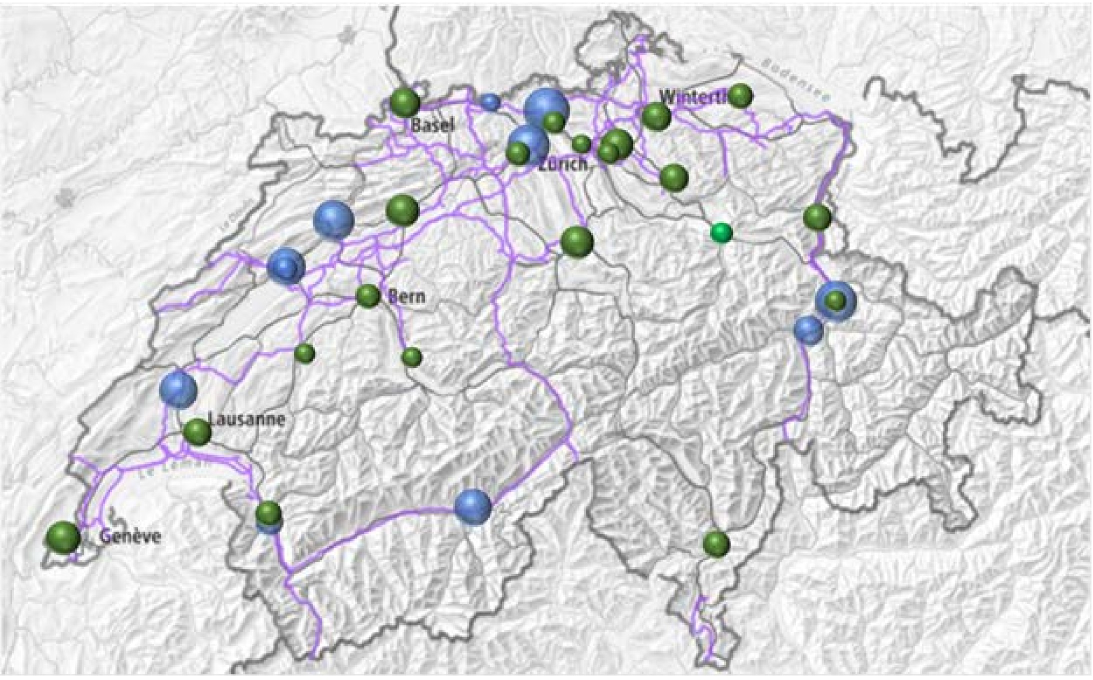


Figure 2.1: Large emitters and current natural gas pipeline network in Switzerland

Currently, none of these plants has a capture facility – it is expected that the current study should provide an indication of optimal conditioning parameters (water content and purity) for the CO2.

The CO2 collecting network subject of the present study will transport the captured CO2 stream up to a delivery point, from where a long transmission pipeline will deliver the CO2 to a selected location, for final sequestration.

Two options are possible:

- Transmission towards the North could start in Basel

- Tansmission towards South should be assumed to be in Collombey, where an existing oil pipeline leads to Genoa

The transmission pipeline is not part of the current SoW.

It is requested that the new pipeline network to follow the existing natural gas pipelines corridors as much as possible. Furthermore, the possibility to use decommissioned gas pipeline sections is to be considered. A specific effort shall be made to clarify possible configurations for the Kanton of Zurich, where different scenarios are possible to connect additional smaller point sources.

3. CO2 COLLECTION PIPELINE NETWORK DEVELOPMENT

A useful starting point for the iterative design is a layout with 2 trunk lines as shown in Figure 3.1, including two main trunklines, called Eastern and Western Lines respectively.

These two trunklines will collect CO2 from different emitters in their relevant areas, according to a phased program. In a first phase, they will collect CO2 produced by the larger emitters only, while in a second phase, the full network will be developed, connecting all emitters, with individual connection cost for plants outside the first group.

A deep dive will be performed for the Kanton Zurich, to understand if and in which configuration a set of smaller point sources can be connected to the network.

The reference design standard for this project is ISO 27913-2016, “Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems”.

Other standards or guidelines (as for instance DNVGL-RP-F104, see Section 1.4) could be considered in case of some supplemental requirements, if any.

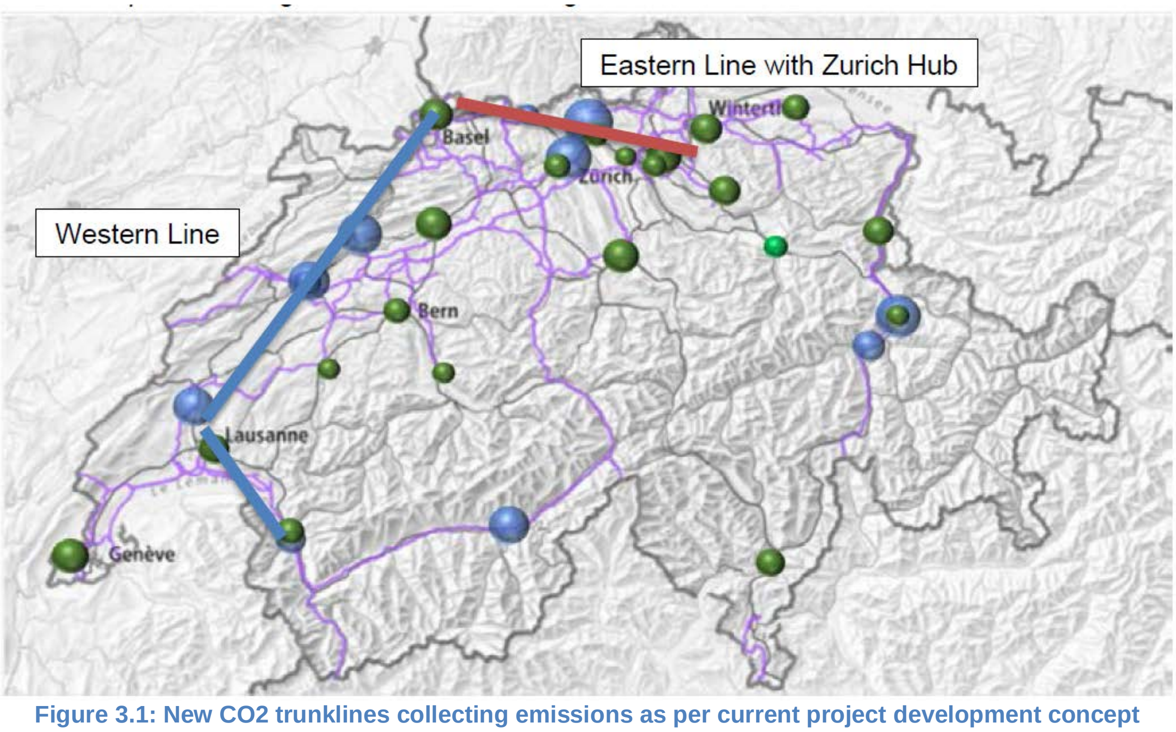


Figure 3.1: New CO2 trunklines collecting emissions as per current project development concept

The conceptual study for the new pipeline system will be carried out by determining its configuration in terms of pipeline routes, lengths, depth of lay, material, diameter, wall thickness and other relevant specifications, specifications of monitoring and safety equipment as well as operational characteristics like purity/ water content requirements, as well as number, spacing and configuration of pressure boosting stations.

The optimization analysis of the transport system, to define the pipeline diameter, the number/size of pressure boosting stations and their construction schedule (phasing) is based on the minimization of investment (CAPEX) and operating (OPEX) costs, by evaluating all the possible alternative transport configurations.

The optimization technique is based on the criteria to calculate a transportation cost-index (ATCI, actualized transport cost index) for the unit volume of fluid, and to compare it for all the investigated alternatives. The alternative having the lowest transportation cost-index will be the “optimum configuration” to be selected.

The transportation cost-index ATCI is calculated on the basis to amortize the investment and operating costs at the end of the project lifetime, by considering money interest and inflation.

To calculate the Actualized Transport Cost Index (ATCI), the investment cost and the operating cost are adjusted to each year of operation by means respectively of amortization and the inflation rates, starting from the start up year.

While the costs are all evaluated at the initial construction time and then actualized at the effective investment time, on the basis of the investment costs inflation rate, the ATCI is calculated by actualizing the sum of all the costs and the flow rates at the initial operating time when the amortization process begins.

The adopted optimization procedure makes reference to the methodology described in R.H. Perry, D. Green, "Perry’s Chemical Engineers' Handbook", 6th Edition, McGraw-Hill New York, 1984 (Ref. [4]).

The general methodology of work development is as reported in Appendix A, Section 2 of Ref. [3].

4. PIPELINE DESIGN DATA

4.1 FLUID SOURCE DATA

In the below Table 4.1 the list of the considered big emitters is reported together with the respective location.

Table 4.1: List of CO2 emitters – Location

Emitter	Longitude	Latitude
Holcim (Schweiz) AG	8.2391	47.5217
Jura Cement Fabriken	8.1568	47.4147
Holcim (Schweiz) AG	9.5529	46.9155
Vigier Cement AG	7.2493	47.1848
Varo Refining Cressier SA	7.0358	47.0400
Holcim (Suisse) SA	6.5464	46.6557
LONZA AG	7.8882	46.2967
Les Cheneviers	6.0322	46.1942
Renergia Zentralschweiz AG	8.3760	47.1135
KEBAG AG	7.5706	47.2153
ERZ KHKW Hagenholz	8.5653	47.4142
IWB Basel	7.5833	47.5467
Axpo Tegra AG	9.4246	46.8263
KVA Winterthur	8.7526	47.4981
KEZO Hinwil	8.8206	47.3083
TRIDEL Lausanne	6.6392	46.5277
VfA Buchs	9.4836	47.1756
Cimo SA	6.9653	46.2529
ACR Giubiasco	8.9887	46.1722
SATOM Monthey	6.9600	46.2781
KVA Thurgau	9.1383	47.5575
Energiezentrale Forsthaus (KVA)	7.4139	46.9515
Juracime SA	7.0296	47.0340
GEKAL Buchs	8.1035	47.3890
KVA Turgi	8.2678	47.4844
ERZ KHKW Josefstrasse	8.5222	47.3867
KVA Linth	9.0400	47.1350
GEVAG Trimmis	9.5570	46.9161
AVAG KVA AG	7.6062	46.7621
SAIDEF Fribourg	7.1218	46.7725
KVA Limmattal	8.4030	47.4166
DSM Nutritional Products AG - Werk Sisseln	7.9786	47.5476

In the below Table 4.2 the list and location of the emitters to be considered for the analysis of the network configuration in the Kanton of Zurich.

Table 4.2: List of CO2 emitters for kanton of Zurich

Kanton of Zurich Emitter	Longitude	Latitude
KVA Limmattal	8.4031	47.4166
ARA Werdhölzli	8.4814	47.4009
KVA Hagenholz	8.5647	47.4142
HKW Aubrugg*	8.5755	47.4119
ERZ KHKW Josefstrasse	8.5222	47.3867

** as per Client indications, HKW Aubrugg will not be considered, being a small emitter and due to lack of information relevant to emission rate.*

4.2 FLUID DELIVERY POINTS

The list and location of the 2 proposed delivery points are reported in the below Table 4.3.

The proposed network configuration shall be capable to deliver the CO2 to both the delivery points.

It will be possible to operate the western trunkline in both directions: to Basel and to Collombey. This will increase the system flexibility in case of unavailability of one of the two delivery points.

The eastern trunkline will be designed considering all the Eastern emitters being routed to Basel delivery point. In case this delivery point is not available, it will be evaluated the possibility not to capture the CO2 at some Eastern emitter in order to reduce the trunkline flowrate and the system pressure drop up to Collombey area (located on the western side of the country).

Table 4.3: Proposed CO2 delivery points

Proposed CO2 Delivery Points	Longitude	Latitude
Basel area (North Option)	7.8973	47.5827
Collombey area (South Option)	6.9562	46.2967

4.3 FLUID DATA

The produced CO2 stream will come from post-combustion capture units installed at each emitter location. Hence, the CO2 at battery limit with the transport system will be a wet stream saturated at capture exit conditions, assumed at atmospheric pressure and 30°C. The CO2 Stream Expected Molar Composition is considered the same for all emitters and it is reported in the below Table 4.4 (as dry component). The below composition is based on a typical post combustion CO2 composition (refer to Table 3-5 of Ref.[5]).

Table 4.4: CO2 Stream Expected Molar Composition

Component	Molar fraction
	%
CO2	99.793

CH4	0.010
N2	0.170
C2+	0.010
CO	0.001
O2	0.010
Nox	0.005
Sox	0.001

4.4 FLOW RATE, PRESSURE AND TEMPERATURE BOUNDARY CONDITIONS

Pressure and temperature boundary conditions are derived from typical value of the adopted CO2 capture technology (i.e. post-combustion). In particular, as per Section 4.3, the following battery limit conditions (i.e. at the exit of the capture plant, which is the suction of compression system) are considered at the source locations:

- CO2 Temperature = 30°C
- CO2 Pressure = 0 barg

CO2 will be then compressed up to the required value for each transport option. Coolers will be installed at each compressor stage in order to limit the CO2 temperature to 45°C maximum (a typical maximum value for pipeline transport conditions).

The list of CO2 Design Flow Rate for each emitter is reported in the below Table 4.5 and Table 4.6 for the big emitters and the Zurich Kanton emitters respectively.

A margin of 20% on the reported CO2 emissions will be considered for the CO2 collection network design. This corresponds to a margin of around 30% on the CO2 transport capacity in the network, taking into account the following factors:

- CO2 capture technology efficiency is 90% of the reported CO2 emitter rates
- Concentrated pressure drops and pipeline routing uncertainties: 10% margin assumed
- Allowance for future expansion: 20% margin assumed

Table 4.5: CO2 design flowrate for each emitter

Emitter	CO2 emission tons /year
Holcim (Schweiz) AG	554525
Jura Cement Fabriken	470420
Holcim (Schweiz) AG	454534
Vigier Cement AG	436943
Varo Refining Cressier SA	383397
Holcim (Suisse) SA	378731
LONZA AG	366000
Les Cheneviers	302109

Renergia Zentralschweiz AG	286633
KEBAG AG	284165
ERZ KHKW Hagenholz	400000 (1)
IWB Basel	242466
Axpo Tegra AG	240758
KVA Winterthur	225058
KEZO Hinwil	218391
TRIDEL Lausanne	211173
VfA Buchs	206530
Cimo SA	196403
ACR Giubiasco	188451
SATOM Monthey	175945
KVA Thurgau	166128
Energiezentrale Forsthaus (KVA)	160122
Juracime SA	158841
GEKAL Buchs	156884
KVA Turgi	133752
ERZ KHKW Josefstrasse	126305
KVA Linth	123254
GEVAG Trimmis	122020
AVAG KVA AG	113260
SAIDEF Fribourg	112836
KVA Limmattal	103622
DSM Nutritional Products AG - Werk Sisseln	100893

Note (1): Expected Rate after 2025

Table 4.6: CO2 design flowrate for each emitter of Zurich Kanton

Emitter	CO2 emission tons /year
KVA Limmattal	103622
ARA Werdhölzli	40000
ERZ KHKW Hagenholz	400000 (1)
ERZ KHKW Josefstrasse	126305

Note (1): Expected Rate after 2025

The minimum delivery pressure at pipeline arrival location is considered equal to:

- 10 barg, in case of gaseous phase transportation;
- 85 barg in case of dense phase transportation (Ref.[5]).

The maximum operating pressures at pipeline inlets are considered equal to:

- 35 barg, in case of gaseous phase transportation;
- 140 barg in case of dense phase transportation (in order to keep the design pressure within #900 limit).

- For urban and densely populated areas, due to risk analysis evaluation, it is possible that high pressure pipelines cannot be installed. In case of emitters located in such areas, sensitivity calculations will be performed considering the following maximum operating pressure for the flowlines: 5/10/15 barg.

4.5 ENVIRONMENTAL CONDITIONS

Air temperature annual trends in Zurich, Basel and Sion are reported in the below Table 4.7 (Ref.[6]).

Table 4.7: Air Temperature annual trends in Zurich, Sion and Basel.

Zurich	**°C**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
		-0.7	0.7	4.3	8.5	12.9	16.2	18.0	17.2	14.1	8.9	3.9	0.3	8.7
Sion	**°C**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
		-0.2	1.7	6.2	9.9	13.8	16.7	19.5	18.5	15.5	10.8	4.5	1.2	10.0
Basel	**°C**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
		1.1	3.1	5.7	8.5	13.0	16.1	18.3	17.8	14.3	9.3	4.8	2.0	9.5

Based on Saipem internal database, the soil type along the route is expected to be a clay/rock type, with a thermal conductivity of 1.5 W/mK.

Based on the above, the annual soil temperature trend at a burial depth of 1 meter can be calculated for the 3 locations (refer to the below Figure 4.1, Figure 4.2 and Figure 4.3). The following minimum and maximum temperatures can be considered as representative of winter and summer conditions:

- Minimum soil temperature at 1 m burial depth = 3°C
- Maximum soil temperature at 1 m burial depth = 16°C

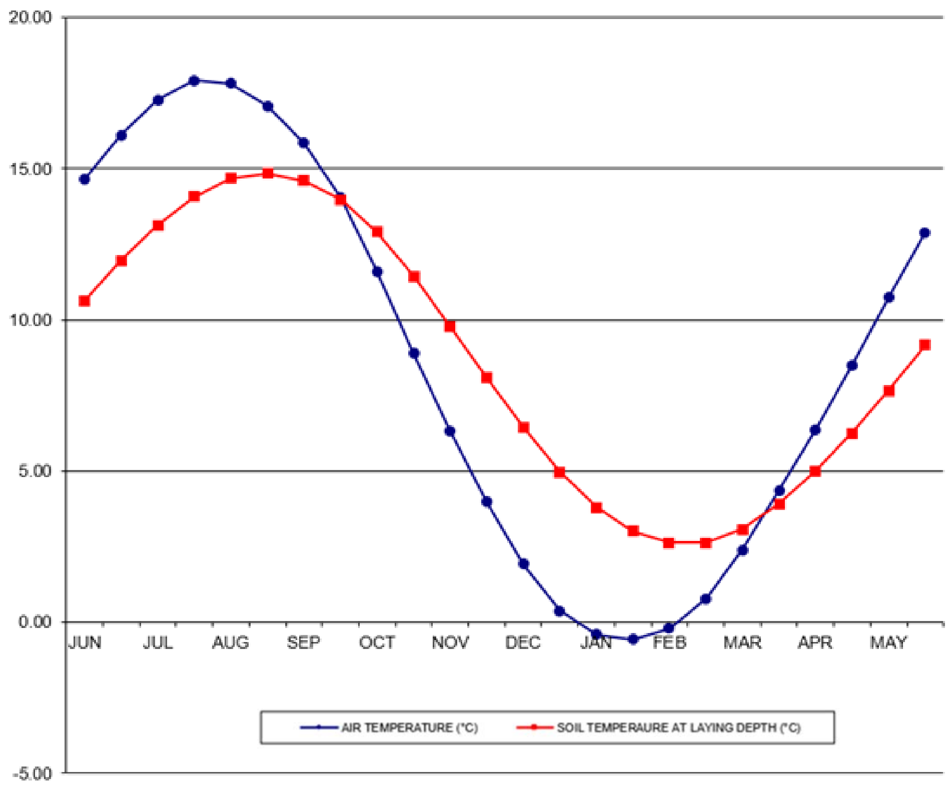


Figure 4.1: Annual Trends of Air Temperature and Soil Temperature at Burial Depth in Zurich

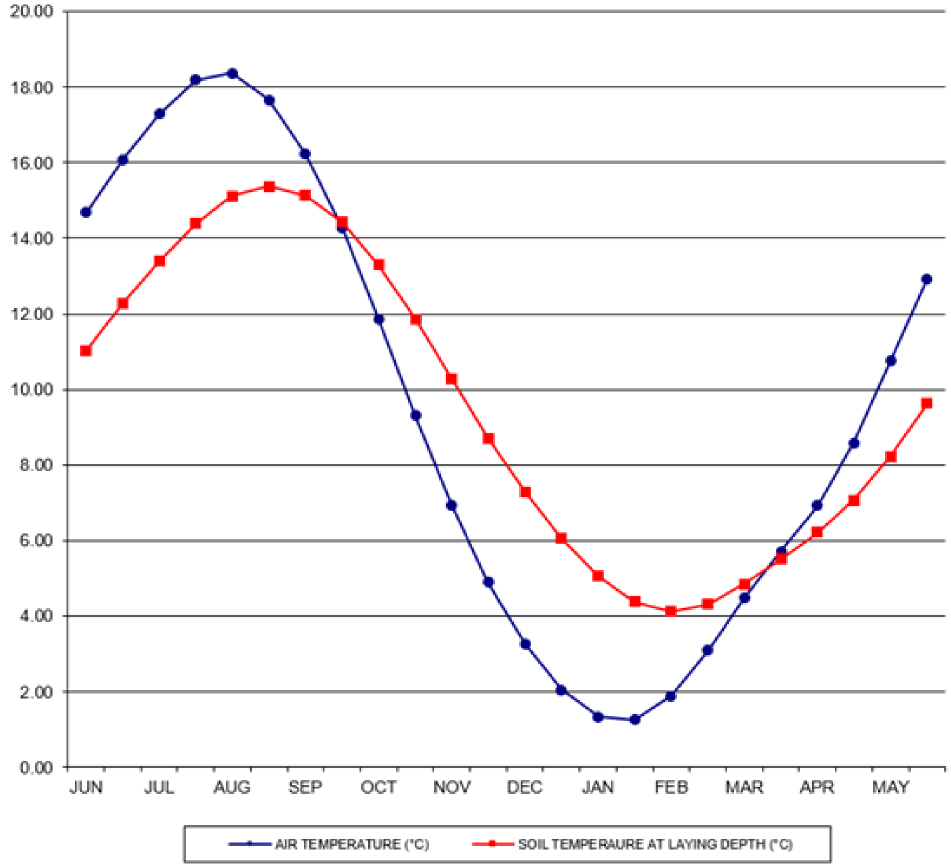


Figure 4.2: Annual Trends of Air Temperature and Soil Temperature at Burial Depth in Basel

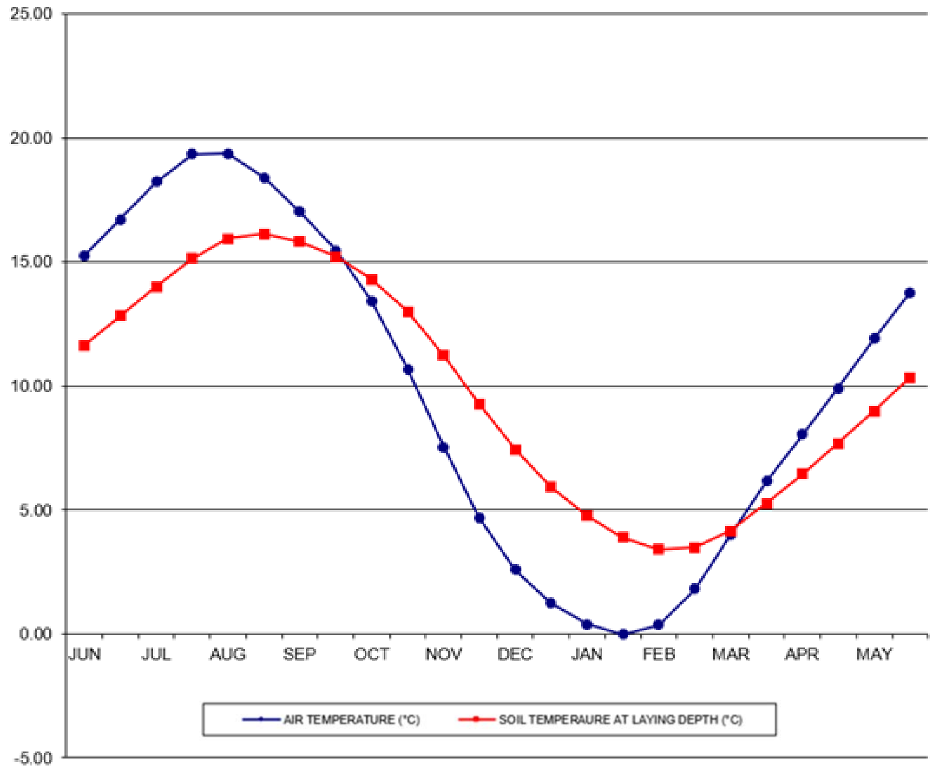


Figure 4.3: Annual Trends of Air Temperature and Soil Temperature at Burial Depth in Sion

4.6 EXISTING PIPELINE DATA

Based on September 24th Meeting with VBSA-ETH-Gas Operators, the whole CO2 collection system will be brand new, as no existing pipeline is available for conversion.

4.7 EXISTING PIPELINE CORRIDOR DATA

Information relevant to existing pipeline corridors have been extracted from the Swiss Federal Geoportal (Ref.[7]). Figure 4.4 reports an overview of the existing natural gas network in Switzerland.

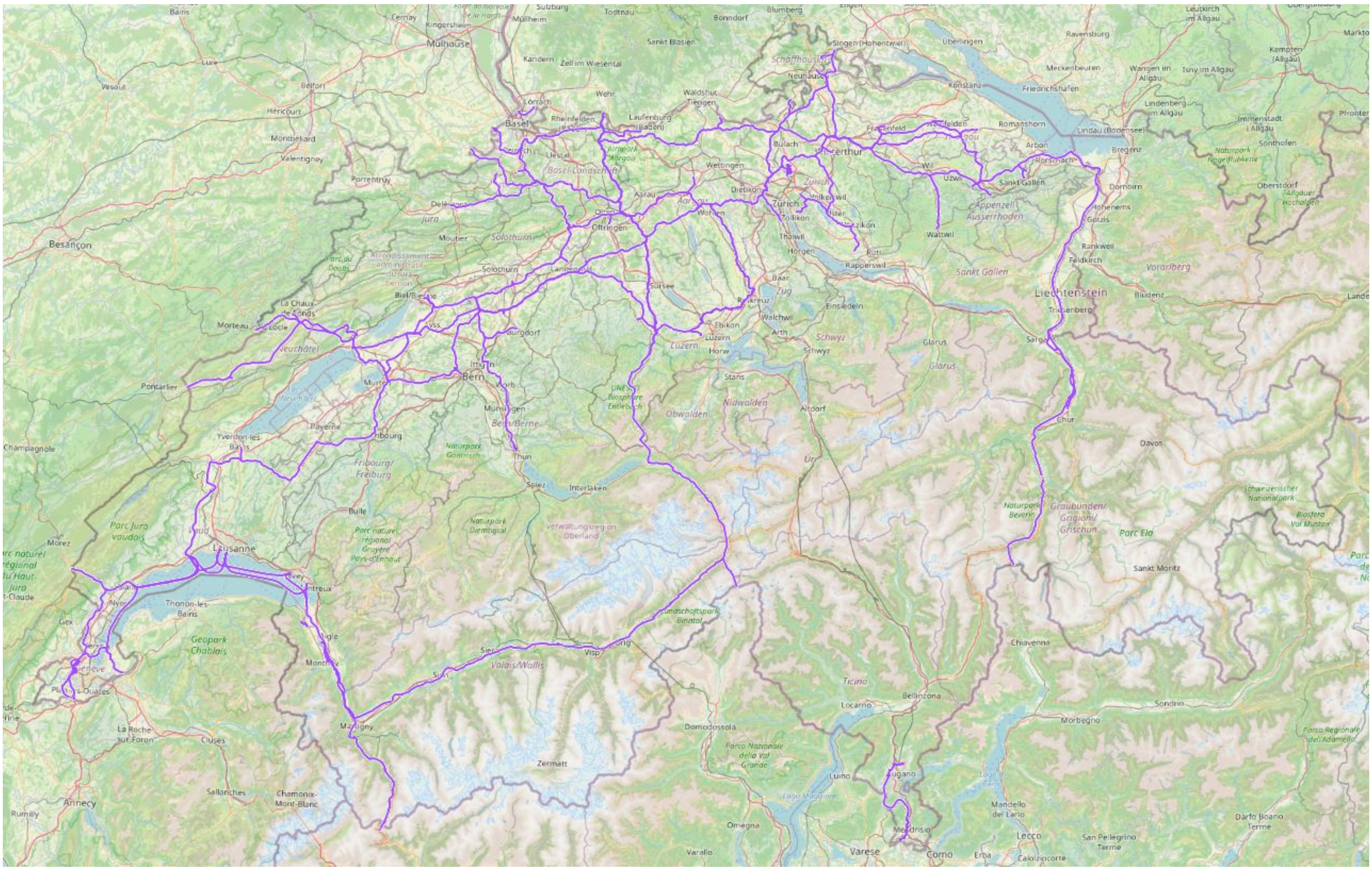


Figure 4.4: Existing high pressure gas network (Ref.[7])

The new CO2 collecting network routing will follow the existing pipeline corridors wherever possible.

5. APPENDIX A – PRELIMINARY PIPELINE ROUTING AND ELEVATION PROFILE

In the following Figure 5.1 and Figure 5.2, the preliminary pipeline routings are reported for Eastern Trunkline and Western Trunkline respectively, assuming Basel as delivery point (North Option).

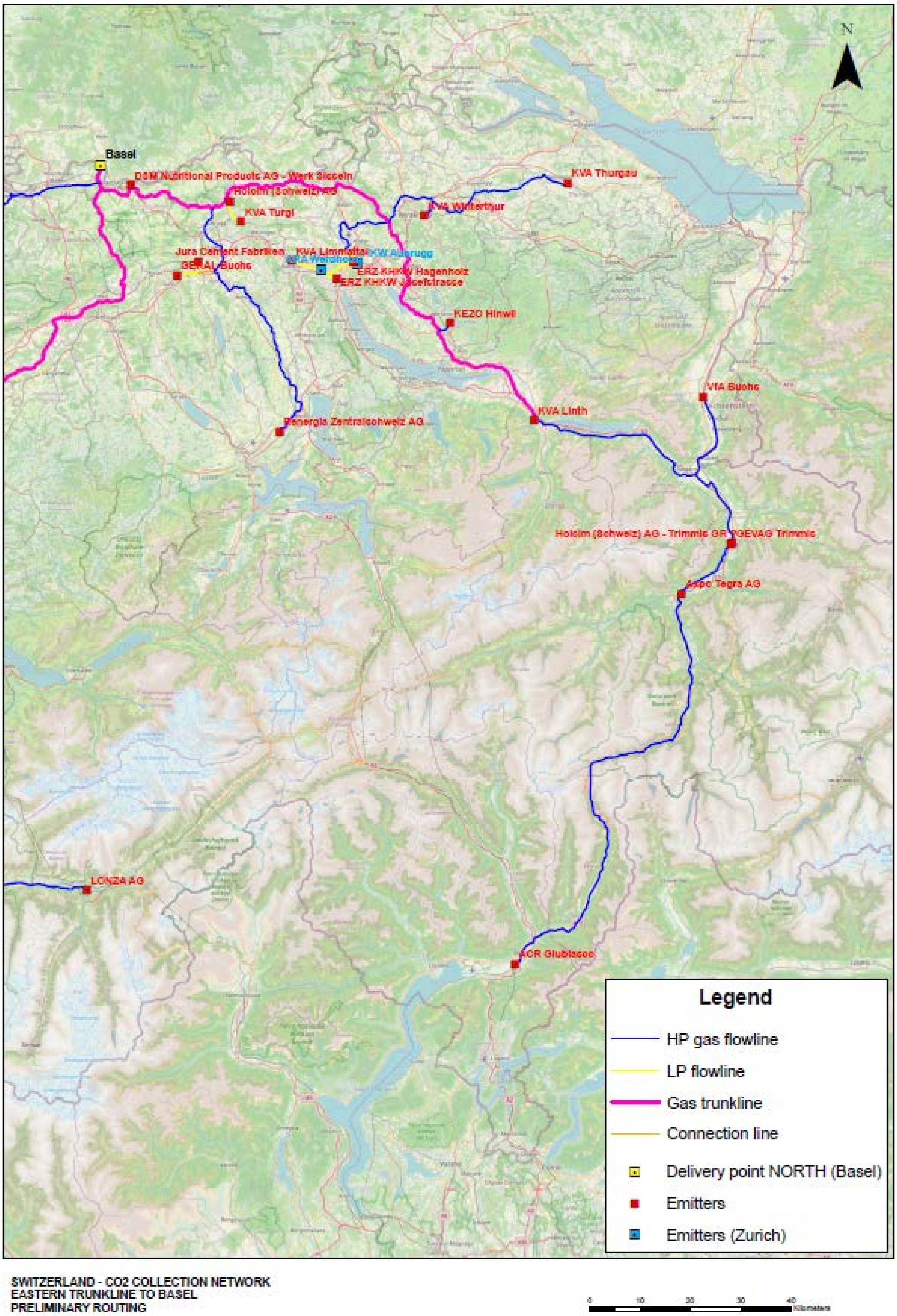
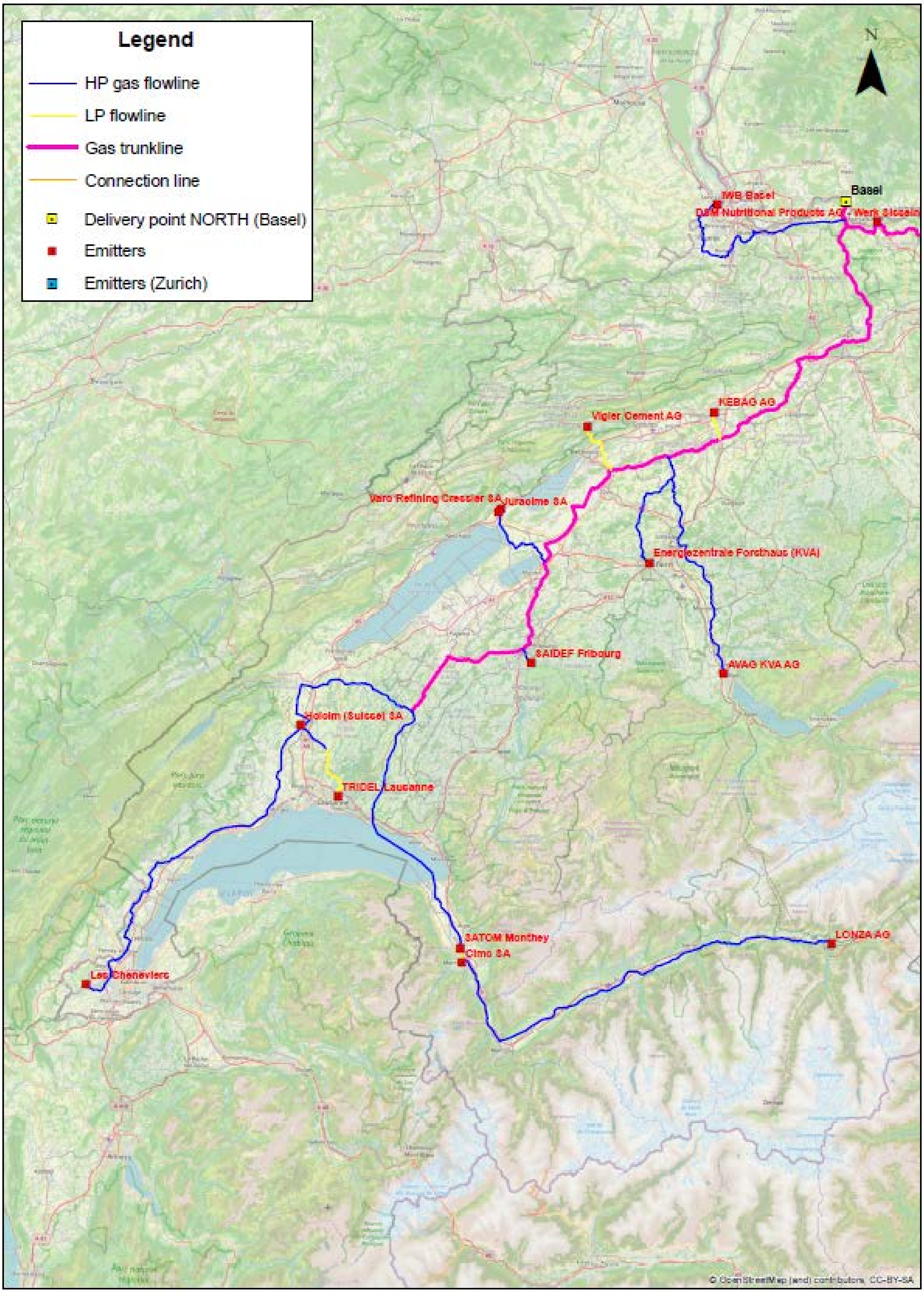


Figure 5.1: Eastern Trunkline to Basel – Preliminary Routing



SWITZERLAND - CO2 COLLECTION NETWORK
WESTERN TRUNKLINE TO BASEL
PRELIMINARY ROUTING

0 10 20 30 40 Kilometers

Figure 5.2: Western Trunkline to Basel – Preliminary Routing

In the following Figure 5.3 and Figure 5.4, the preliminary pipeline elevation profiles are reported for Eastern Trunkline and Western Trunkline respectively, assuming Basel as delivery point.

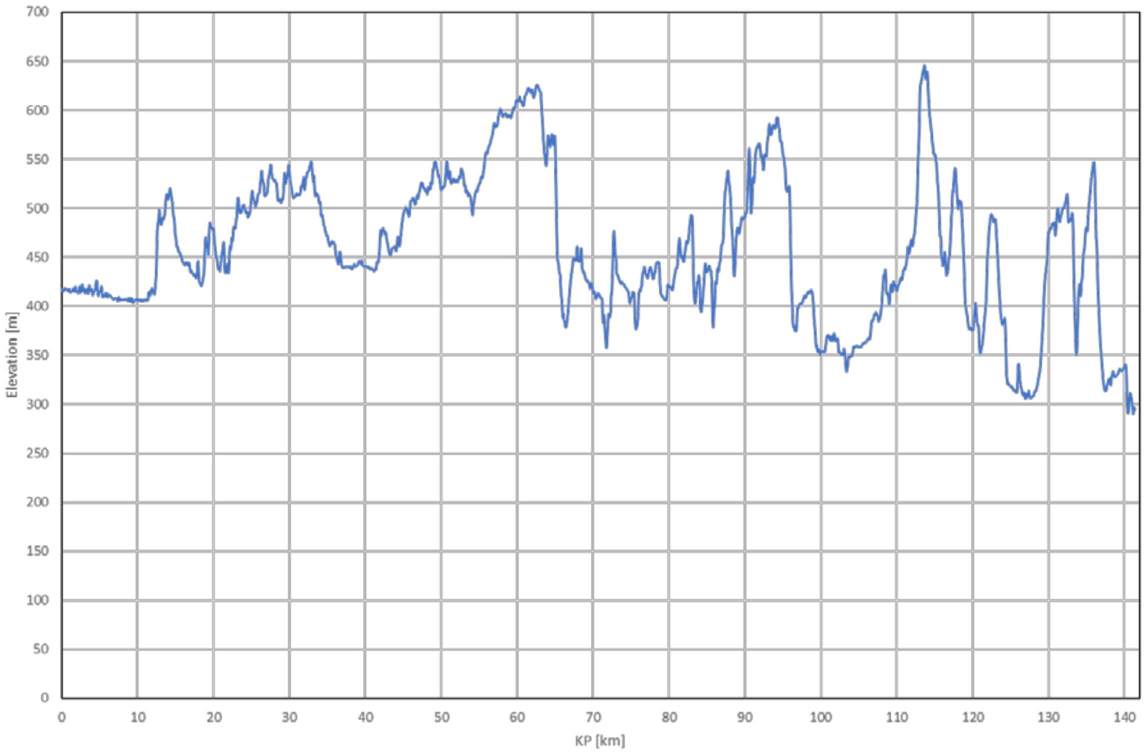


Figure 5.3: Eastern Trunkline to Basel – Elevation Profile

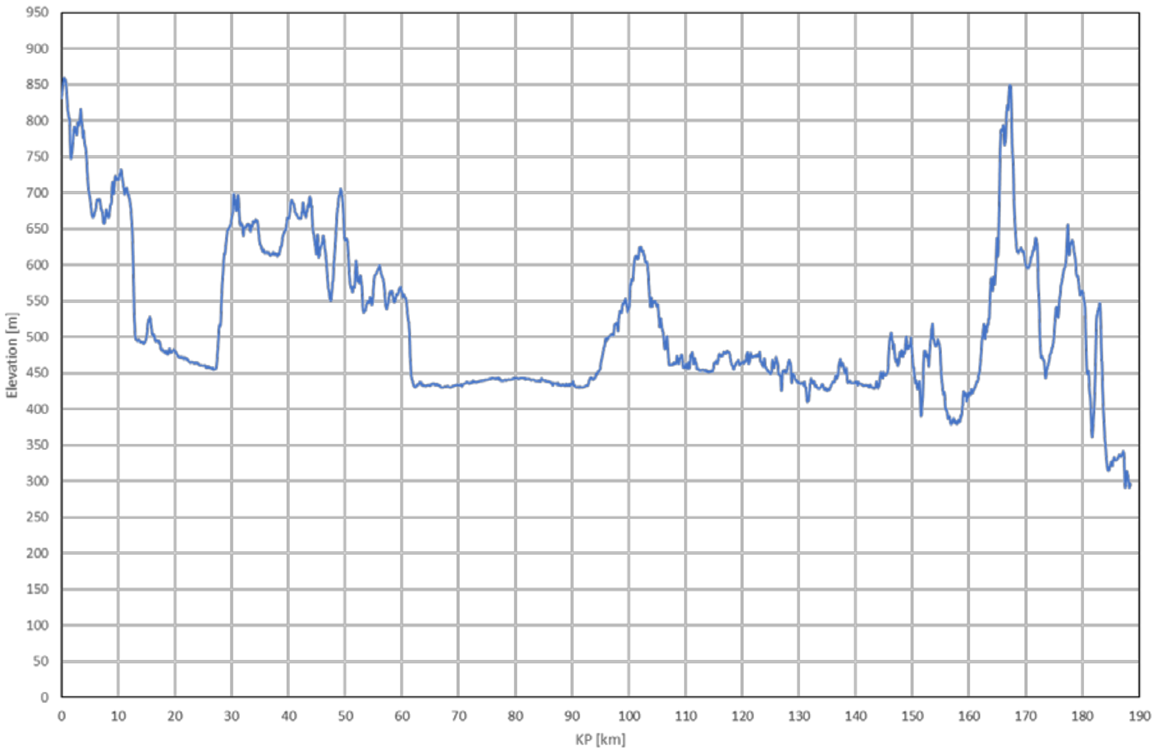


Figure 5.4: Western Trunkline to Basel – Elevation Profile