Very Large Hadron Collider

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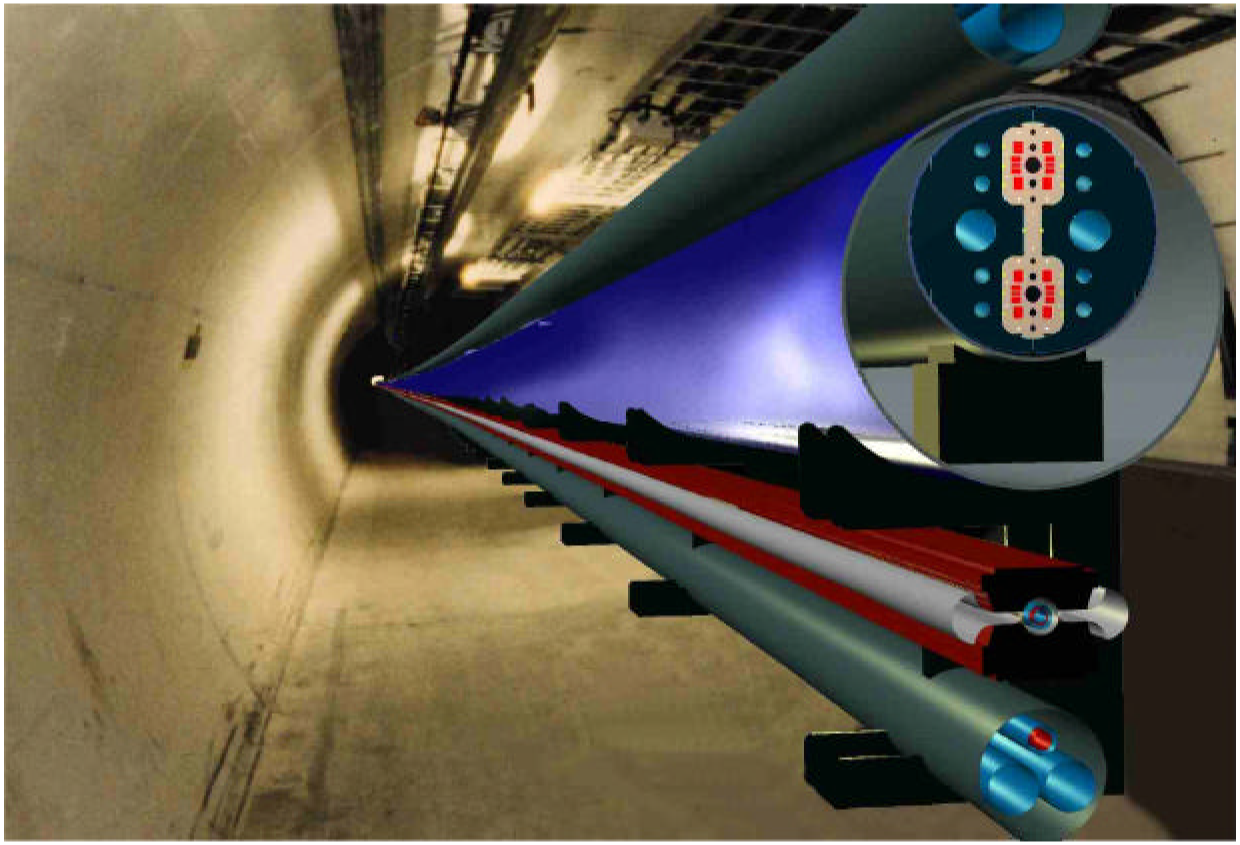
www.vlhc.org

Design Study for a Staged Very Large Hadron Collider



The Design Study of a Staged VLHC

- This design study of a staged VLHC showed us that:
  - A staged VLHC starting with 40 TeV and upgrading to 200 TeV in the same tunnel is completely feasible.
  - There are no major accelerator physics or technical obstacles.
  - The cost of the first stage of the VLHC is comparable to that of a linear electron collider.
  - There are many opportunities to decrease the cost through R&D and engineering studies.
  - The VLHC fits into and should be considered part of a rational worldwide high-energy physics plan that includes a linear electron collider.

The Presentation to the Fermilab AAC

- The order of the presentation:
  - o Introduction and description of the concept — P. Limon
  - o Accelerator physics for Stage 1 and Stage 2 VLHC — M. Syphers
  - o Stage 1 VLHC systems and technology — G. W. Foster
  - o Conventional construction — P. Garbincius
  - o Cost analysis, R&D, and future needs — P. Limon

Finding The Right Plan for High-Energy Physics

- The right plan will match the tools we build to the physics we seek to understand.
- The right plan will have a vigorous program to develop new and better accelerators and experiments.
- The right plan will be a coordinated worldwide plan, with every region represented and involved intellectually and financially.

The Tools of High-Energy Physics

Precision measurements

- Lepton colliders are used to make precision measurements of known spectroscopy.

Anomalies

- Specialized accelerators, beams and experiments illuminate the dark side, such as neutrino mass, CP violation, particle cosmology, etc.

Big discoveries

- Very-high-energy hadron colliders probe deep into the unknown and make discoveries at the energy frontier.

The Energy Frontier

- The most exciting physics is at the energy frontier
  - Someone, somewhere will advance to the next energy scale. It will happen.
  - A hadron collider is the only sure way to the next energy scale.
  - The technology of the VLHC is available to us now.
  - Our plan for a staged VLHC makes the energy frontier both affordable and achievable.

A Staged VLHC

- Stage 1 VLHC, 40 TeV collision energy, has about the same cost as a linear collider at 500 GeV.
- The VLHC is much cheaper per unit parton energy.
- The VLHC can be upgraded to 200 TeV.
- The VLHC will define the energy frontier for 50 years.
  - A linear collider may have some nice physics (we don't know that yet), but it will never be at the energy frontier.
  - If we can afford a linear electron collider, we can afford a VLHC.

The Concept

- Take advantage of the space and excellent geology near Fermilab.
  - o Build a **BIG** tunnel.
  - o Fill it with a "cheap" collider.
  - o Later, upgrade to a higher-energy collider in the same tunnel.
    - This spreads the cost and produces exciting energy-frontier physics at each step.
    - It allows more time for the development of cost-reducing technologies and ideas for the challenging high-energy upgrade.
    - A high-energy full-circumference injector into the high-field machine solves some sticky accelerator issues, like field quality at injection.
    - A BIG tunnel is reasonable for advancing to a synchrotron radiation-dominated collider.

The first step

- A VLHC Accelerator Study
  - Requested and charged by the Fermilab Director
  - Based on a Staged Scenario of E_{cm}>30 TeV, Lum>10^{34} first, eventually E_{cm}>150 TeV, L_{peak}>$2x10^{34}$ in the same tunnel.
  - The report is due in May, 2001.
  - The Report will include estimates of the ranges of expected costs and some analysis of the major cost drivers for Stage 1. But it is not a cost estimate for Stage 1 of a VLHC!
  - BNL and LBNL are involved, particularly in accelerator physics, vacuum systems and feedback.
  - We will have international involvement; initially as reviewers, which will be the first step toward forming an international collaboration.

Very Large Hadron Collider

The VLHC Design Study Group

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Preliminary Review

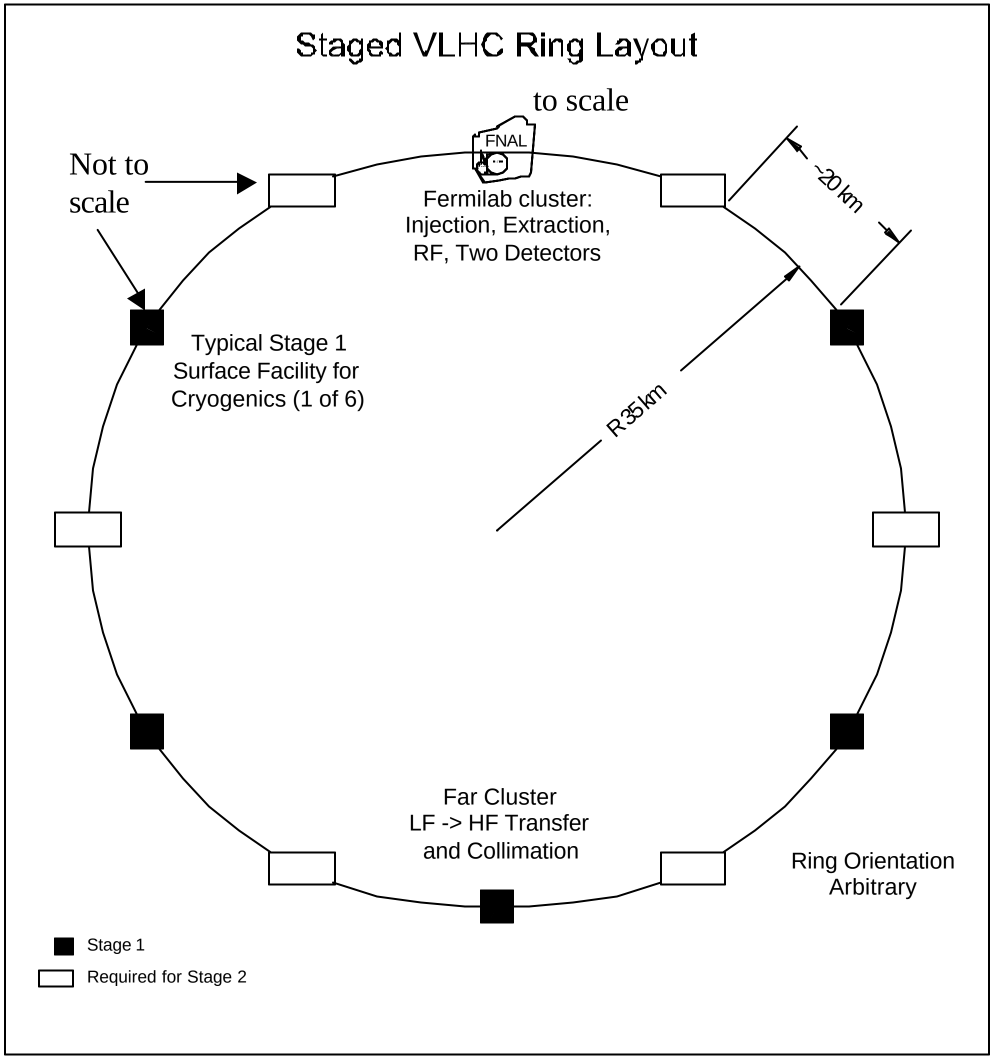
- A preliminary review was held April 30, May 1, 2001, as a check to see if we were way off base before releasing our report.
  - **Review Committee:**
    - Bob Kephart, Fermilab, Chairman
    - Gerry Dugan, Cornell; Jon Ives, consultant; Eberhard Keil, CERN
    - Philippe Lebrun, CERN; Al Zeller, MSU; Erich Willen, BNL;
    - Mike Anerella, BNL
- The reviewers made many good recommendations and observations. They found no serious insurmountable accelerator physics issues. They recognized the need for some cost- and risk-reducing R&D.
- Question: "Have the major cost drivers been identified and is the preliminary cost estimate for Stage 1 of the VLHC reasonable?"
- The Reviewers' Answer: "Although they can and will be improved through focused R&D, the basic technologies on which the Stage 1 VLHC rests are known today. The unit costs quoted to support the estimates can be deemed as rather conservative."

Advantages of Staging

- Each step yields new and interesting physics.
- Stage 1 is at or close to the minimum cost for 40 TeV and its construction greatly reduces the cost of Stage 2.
- It is sited at an existing lab and thus uses the existing intellectual and organizational infrastructure, saving both time and money.
- There are many accelerator physics advantages. For example:
  - A superferric magnet permits injection from Tevatron.
  - Injection at high energy eliminates magnetization and stability issues in the high-energy collider.
  - The initial technology is straightforward, minimizing risk and necessary R&D, and allowing an early start.
  - Staging makes time available for the R&D necessary to solve problems and reduce cost of high-energy phase
- Using the Fermilab (or CERN! or DESY!) existing accelerator complex saves at least $1 billion

Disadvantages of Staging

- It may take longer to get to the highest energy. This is more a political and cost issue than a technical one.
- There may be other scenarios that get to high energy sooner.
  - For example, one could get to an intermediate energy, say 100 TeV, by skipping 2 T magnets and using 5 T for the first step. This might be quicker, although at Fermilab it would require a new injector.
- The initial low-energy design must predict correctly many details of the final high-energy design.
- There will necessarily be a pause in the HEP program while the second collider is installed in the tunnel (five to seven years).
- The plan starts with a very big tunnel, which will have some political difficulties.


Staged VLHC Ring Layout
to scale
FNAL
Not to scale
~20 km
Fermilab cluster:
Injection, Extraction,
RF, Two Detectors
Typical Stage 1
Surface Facility for
Cryogenics (1 of 6)
R 35 km
Far Cluster
LF -> HF Transfer
and Collimation
Ring Orientation
Arbitrary
Stage 1
Required for Stage 2

Very Large Hadron Collider

	Stage 1	Stage 2
Total Circumference (km)	233	233
Center-of-Mass Energy (TeV)	40	175
Number of interaction regions	2	2
Peak luminosity ($cm^{-2}s^{-1}$)	1×10^{34}	2.0×10^{34}
Luminosity lifetime (hrs)	24	8
Injection energy (TeV)	0.9	10.0
Dipole field at collision energy (T)	2	9.8
Average arc bend radius (km)	35.0	35.0
Initial Number of Protons per Bunch	2.6×10^{10}	7.5×10^{9}
Bunch Spacing (ns)	18.8	18.8
?* at collision (m)	0.3	0.71
Free space in the interaction region (m)	± 20	± 30
Inelastic cross section (mb)	100	133
Interactions per bunch crossing at L_{peak}	21	58
Synchrotron radiation power per meter (W/m/beam)	0.03	4.7
Average power use (MW) for collider ring	20	100
Total installed power (MW) for collider ring	30	250

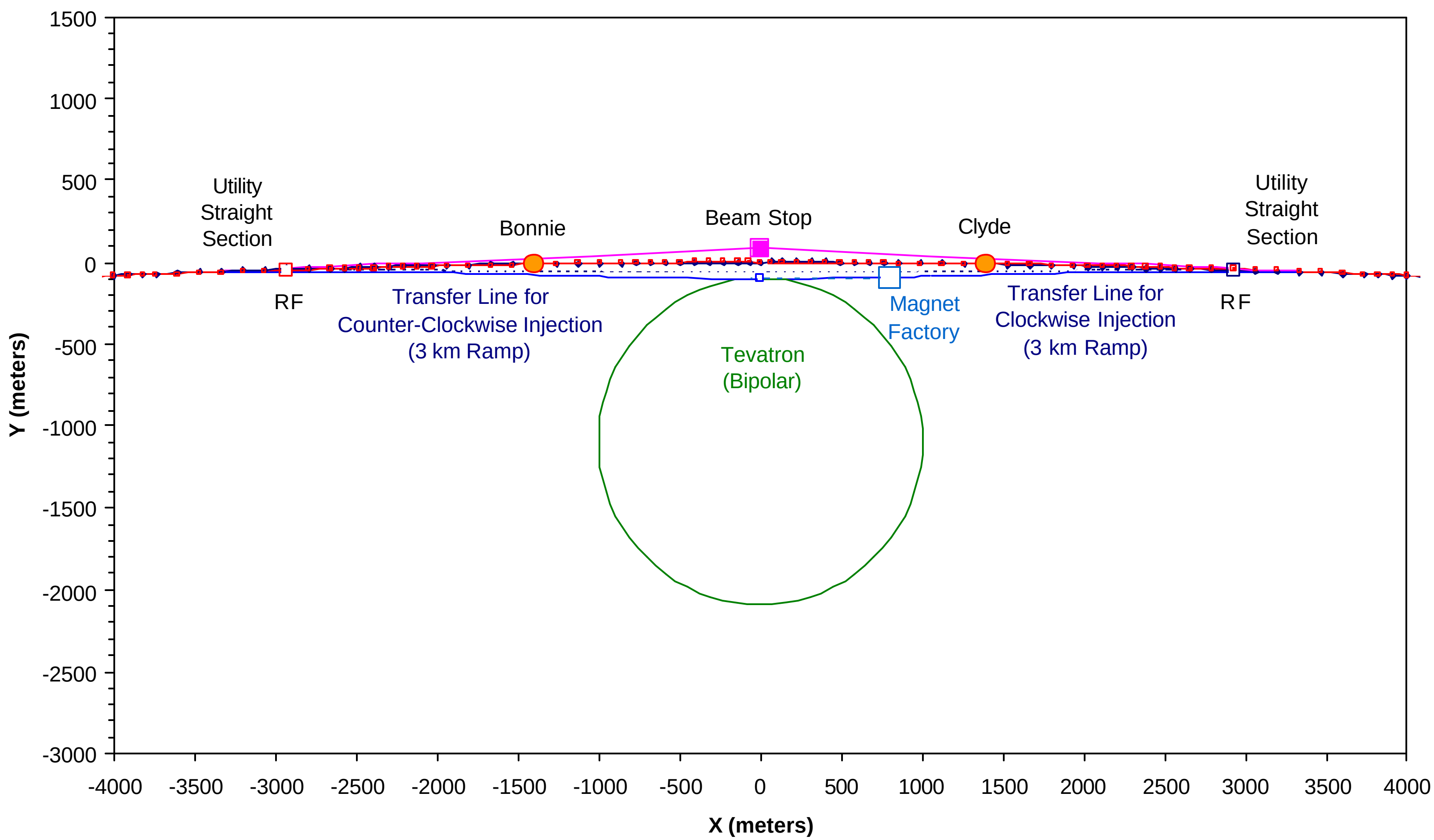
Stage 2

- It is clear that Stage 2 could get to **200 TeV or higher!**

Collision Energy (TeV)		*Magnetic Field (T)*	*Leveled Luminosity ($cm^{-2}s^{-1}$)*	*Optimum Storage Time (hrs)*
Stage 1	**40**	**2**	**1.0×10^{34}**	**20**
Stage 2	**125**	**7.1**	**5.1×10^{34}**	**13**
Stage 2	**150**	**8.6**	**3.6×10^{34}**	**11**
Stage 2	**175**	**10**	**2.7×10^{34}**	**8**
Stage 2	**200**	**11.4**	**2.1×10^{34}**	**7**

Leveled luminosity vs. energy. The luminosity is limited by one or more of the beam-beam tune shift, the synchrotron-radiation power per meter, or the debris power in the interaction region.

VLHC DESIGN STUDY SITE LAYOUT



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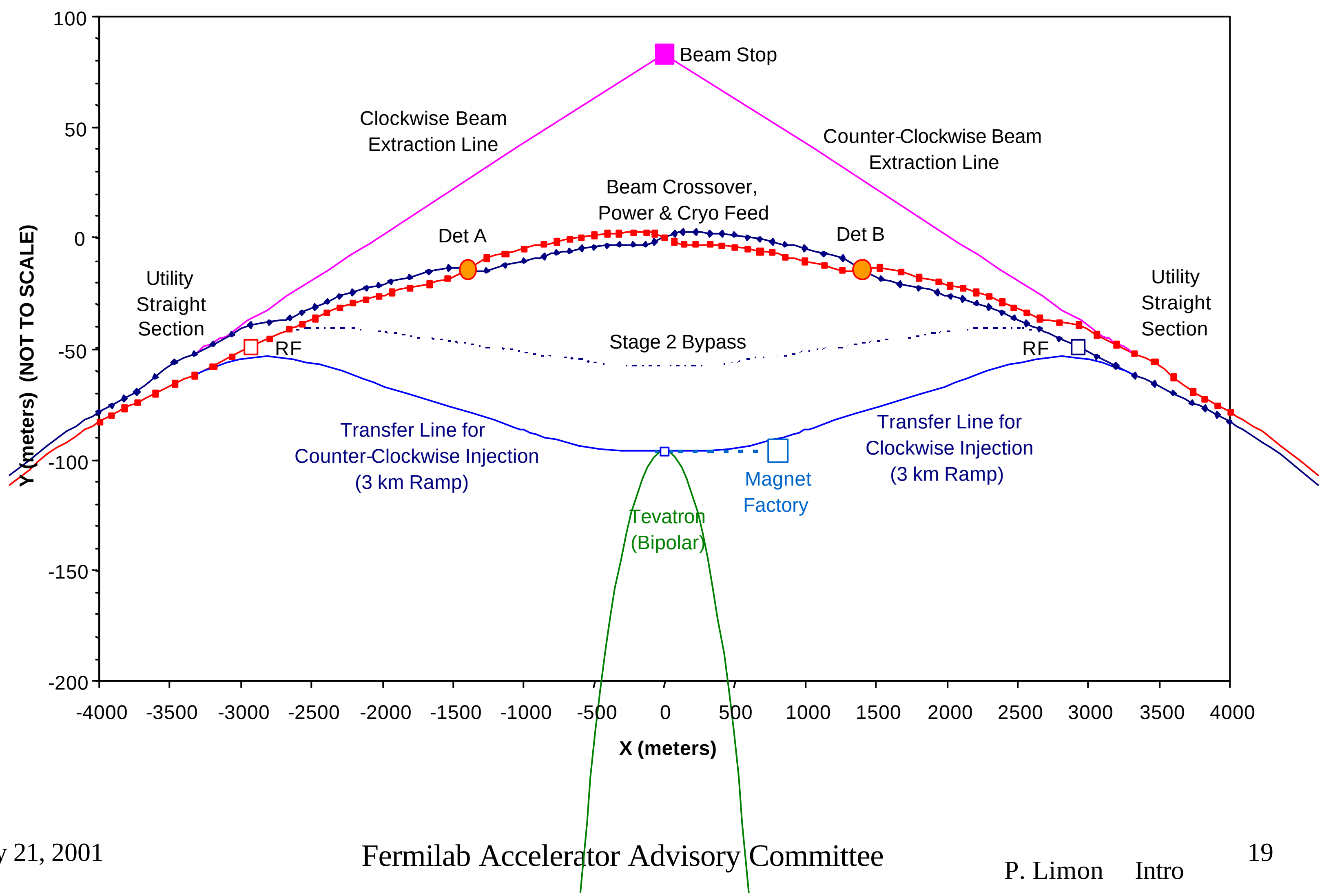
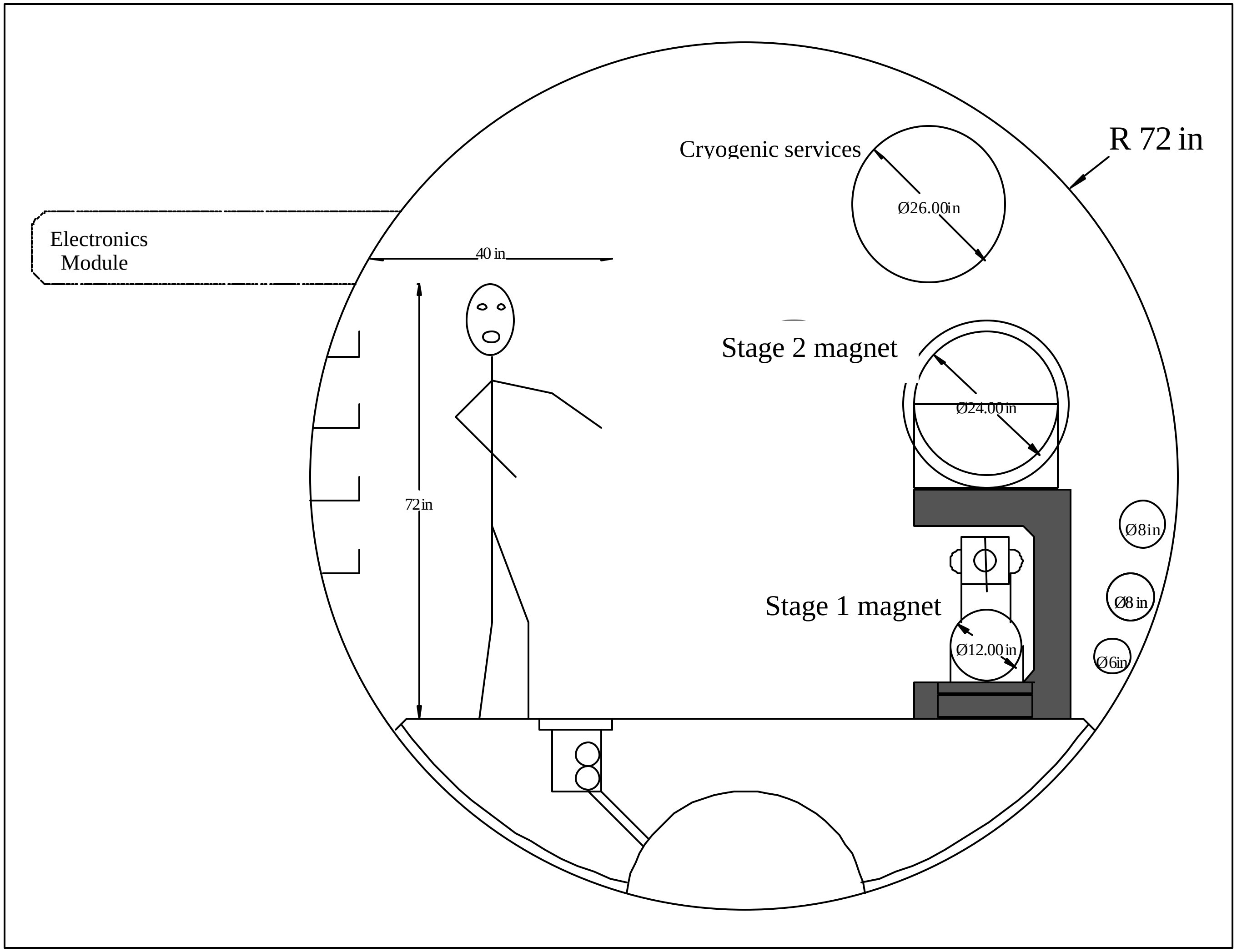
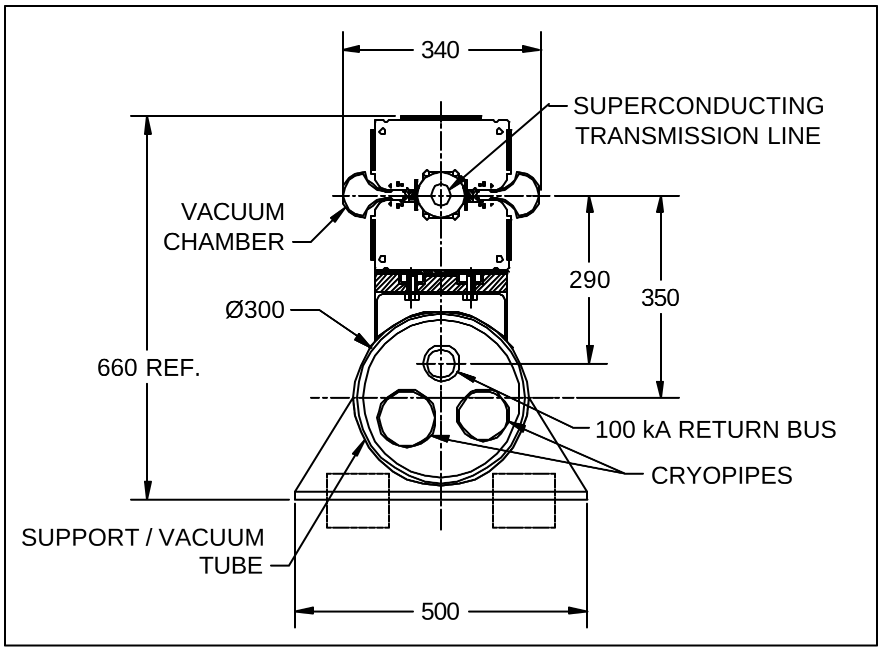
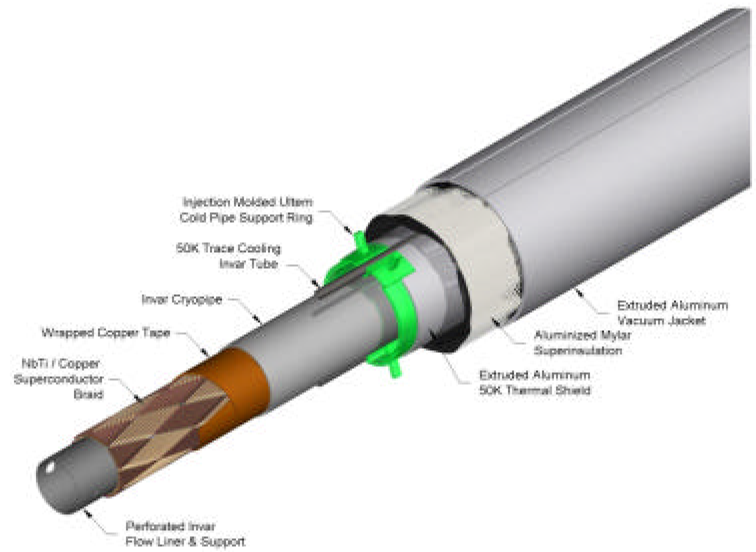



Cryogenic services
Ø26.00in
R 72 in
Electronics
Module
40 in
Stage 2 magnet
Ø24.00in
72in
Ø8in
Ø8 in
Stage 1 magnet
Ø12.00in
Ø6in

VLHC Stage 1 Magnet



Cross-section of Stage 1 superferric magnet



100 kA superconducting transmission line

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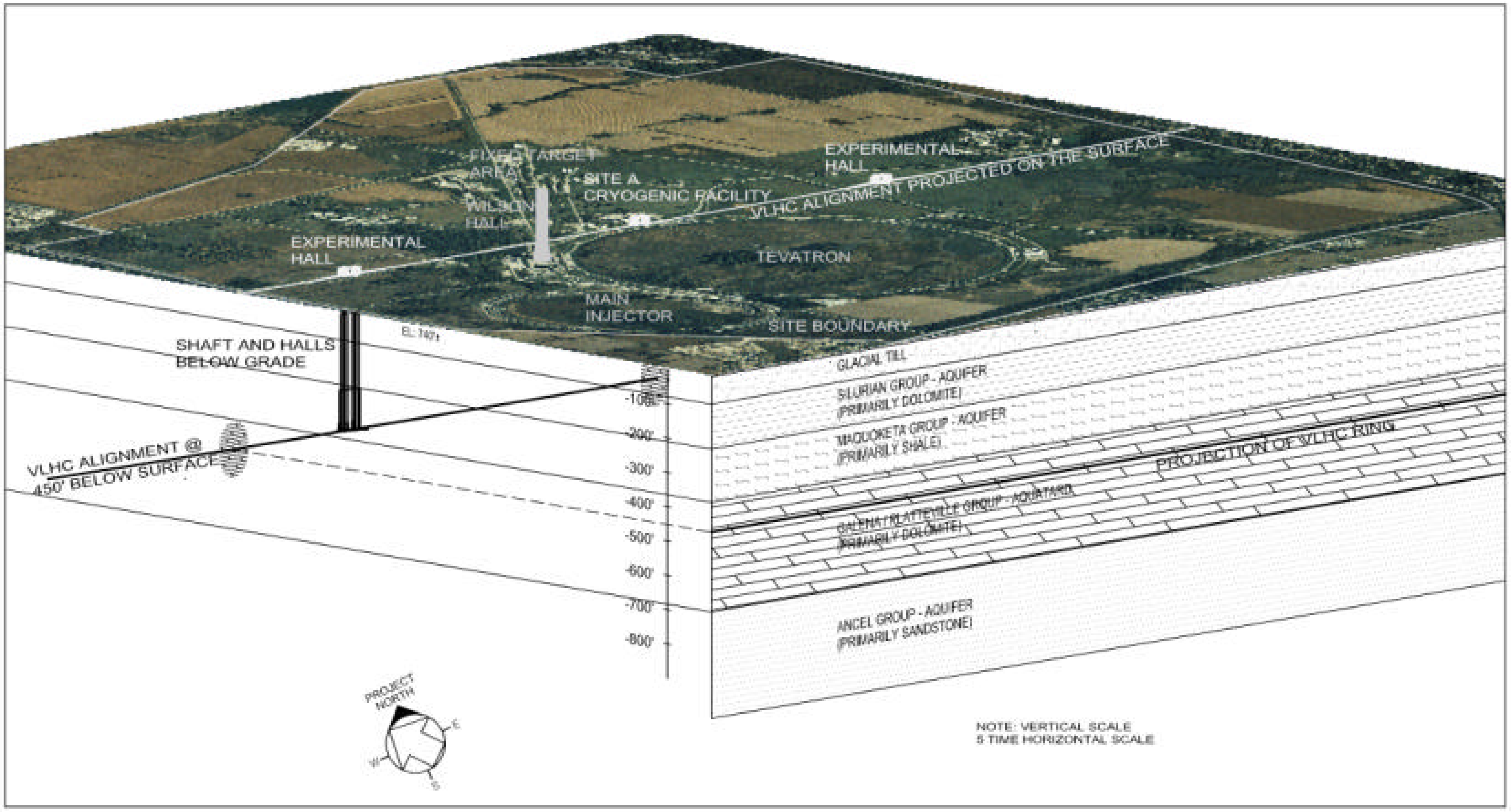

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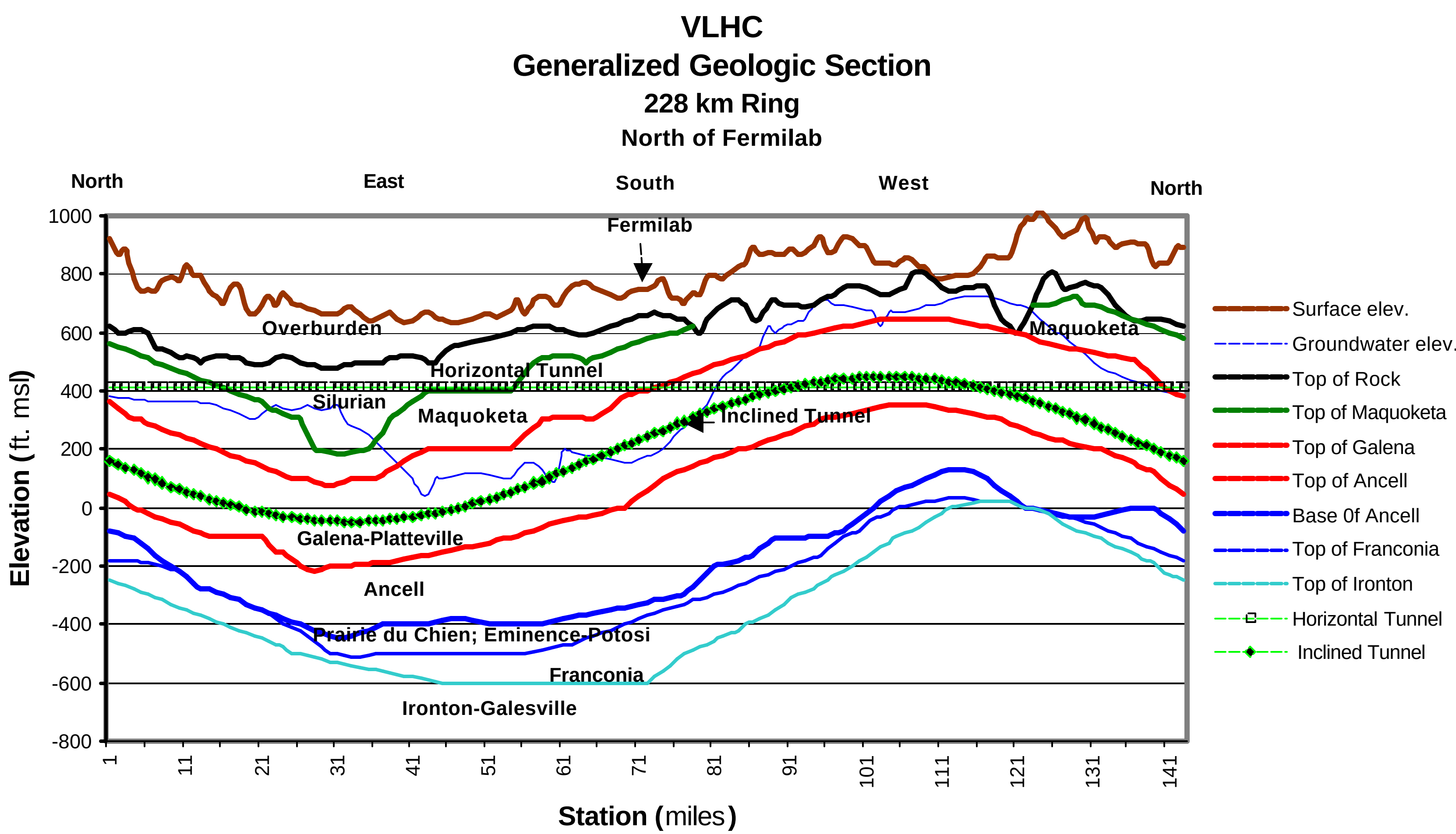

Stage 1 Issues

- Dynamic aperture seems not to be an issue.
- Beam stability at injection needs study. It appears that it can be controlled by straightforward methods, but experiments need to be done to verify this.
- Is this the best way to proceed? How does it compare with other staging options or a no-staging option? A subject for Snowmass.
- The cost analysis results are still uncertain. Continued engineering studies will narrow the uncertainties of the cost analysis.
- What are the public acceptance issues?
- What R&D remains?

Public Acceptance

- We must work on public acceptance from the beginning.
- The old way of "decide, announce, defend" will not work.
- What are the possible public acceptance issues?
  - risk to environment, safety and health;
  - effects on property values;
  - distrust of government;
  - esthetics;
  - perceived lack of community control;
  - appropriate use of government funds;
  - community disruption during construction;
  - perceived lack of participation in decision-making;
  - trust of Fermilab.
- There will be a group studying this issue at Snowmass.

Technical Conclusions of the Study

- There are no serious technical obstacles to the Stage 1 VLHC, although there are improvements and cost savings that can be gained through a vigorous R&D program.
- The Stage 2 VLHC can reach 200 TeV and 2×10^{34} or more in the 233 km tunnel. There is the need for magnet and vacuum R&D, but no insurmountable problems. The luminosity limits are multiple interactions, IP power and luminosity lifetime.
- Making a large tunnel is possible in the Fermilab area. Managing such a large construction project will be a challenge.
- A total construction time of 10 years is feasible, but the logistics will be complex.