

Introduction to the International Space Elevator Consortium

Dr. Dennis H. Wright, International Space Elevator Consortium, dennis.wright@isec.org

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ABSTRACT

The International Space Elevator Consortium (ISEC) has four main thrusts: promote the development of, support and engage in research on, maintain and expand the body of knowledge for, and educate people in the concept and advantages of space elevators. Space elevators are superior to rockets in cost, efficiency and safety. They provide mission opportunities in space enterprise, exploration, science and planetary defense that rockets cannot. In fact, the development of a space elevator infrastructure will revolutionize space commerce and science. Space elevators are closer to reality than many people think: the necessary technology exists or is very close to existing. Development of tether materials has progressed rapidly in recent years and three materials already exist that could support the space elevator. In this presentation, the ISEC mission will be discussed and its programs summarized. Ongoing research includes strong material development, space elevator climber design, tether motion simulation and visualization. Education and outreach brings the space elevator body of knowledge to students, scientists, engineers and the general public. Promotion efforts engage businesses and investors, pointing out not only the viability of space elevators but their tremendous pay-off potential.

PAPER

1. Introduction

Space elevators are superior to rockets in cost, efficiency, safety and lower emissions. They provide mission opportunities in space enterprise, exploration, science and planetary defense that rockets cannot. The development of a space elevator infrastructure will revolutionize space commerce and science.

Space elevators are closer to reality than many people think. As described below, many of the necessary technologies already exist or will exist soon and the International Space Elevator Consortium¹ (ISEC) (logo in Figure 1) has undertaken to explore these and collect and disseminate the latest information on these topics. ISEC is a membership-based charitable organization which promotes the development of space elevators and performs and encourages research in the area. Educating people in the concept and advantages of space elevators is also an essential goal of ISEC.



Figure 1. Logo of the International Space Elevator Consortium

2. Space Elevator Development

The technologies needed to build a space elevator either already exist or are close at hand. This does not mean that there are no challenges. The unprecedented physical size of the project ensures that space elevator development will not be a simple matter of scaling up existing processes. There are numerous operational issues to be addressed as well, such as tether deployment, manufacture and repair in space, atmospheric effects on the tether and space debris, to name a few.

The developmental and operational plan for space elevators and their combination into a space transportation infrastructure constitutes an architecture challenge. The architecture continues to evolve as individual technologies mature.

Based on past study, ISEC believes that all of the above challenges can be met. The most critical of these are the manufacture of the tether, the construction of tether climbers, powering the climber and understanding the dynamics of the tether-climber system.

2.1. Tether Material

The single critical event that made space elevators possible was the advent of strong materials. These had to be strong enough and light enough to support their own weight and that of any payload that ascended or descended tethers made of them. To date, there are three materials that satisfy the stringent strength-to-weight ratio requirements of the space elevator: carbon nanotubes (CNT), single crystal graphene (SCG) and hexagonal boron nitride (hBN). Their structures are shown in Figure 2.

Plans exist to build tethers of each of these materials, but ISEC has focused on graphene. The two-dimensional nature of the macromolecule seems ideally suited to a ribbon shape that will comprise the tether and provide a gripping surface for tether climbers. It has the highest measured strength-to-weight

ratio of any of the candidate materials², as well as many other exceptional material properties such as high electrical and thermal conductivity.

Tens of thousands of layers of SCG will need to be laminated in order to construct the tether. For maximum strength, the layers will need to be precisely positioned with respect to one another so that they form a new material, graphene super-laminate (GSL).

Since the discovery of these materials, there has been extensive study of their properties and methods of production. Because a typical space elevator tether will be 100,000 km long and weigh about three million kilograms or more, the development of large-scale processing of strong materials is essential for the building of space elevators. This will require multiple large factories operating at high speed, in parallel and with high quality control. Nor is the total amount of material the only challenge. Kilometers-long strands of the material will need to be produced so that the strength of the tether is not reduced by splicing together many short pieces.

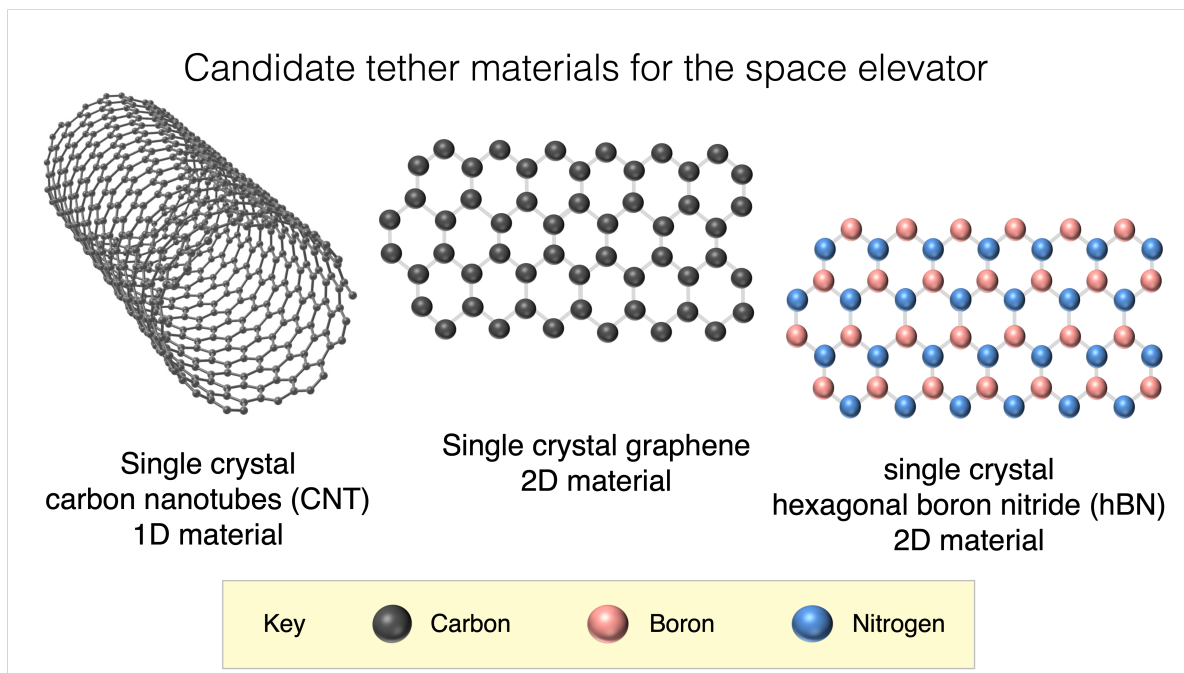


Figure 2. The three possible tether materials

Production rates of kilometers per day of polycrystalline graphene are currently being achieved in South Korea^{3,4}. Although polycrystalline graphene is much weaker than SCG, such rates are encouraging as the same methods could be applied to SCG. Companies have formed to make GSL (multi-layer SCG), at first experimentally. Because these companies are now in the investment-seeking stage, they are not listed here.

2.2. Climbers

After the tether material, the most important space elevator component is the climber. The climber must interact with the tether, by gripping it or otherwise reacting with it to pull itself and its payload upward. An extensive study⁵ was carried out in 2022 and 2023 to examine methods of climber ascent and descent. The study laid out the physics which applies at the interface between the climber and the tether and from this derived the engineering constraints imposed on both the tether material and the climber design.

The tether material met most of these constraints, with improvements required in material shear strength and possibly electrical conductivity.

The climber design was considerably narrowed by the constraints, ruling out electromagnetic drives such as maglev and electrostatic methods. The remaining designs all relied upon friction drives such as gripping wheels and capstans, with gripping wheels becoming the final design. One product of the study was a detailed conceptual design of a climber capable of carrying a 10-ton payload, shown in Figure 3. With the exception of the electric motors, this climber could be built with today's technology. Electric motors with sufficient power and torque are currently being developed.

The power required to drive the climber is the subject of a current ISEC study, to be published in 2026. 4 MW was postulated at the outset of the study, but more will likely be necessary. The key issues are how to transmit the power and how to dissipate the considerable waste heat generated. Conduction through the tether and laser beaming to photo-cell panels on the climber have been considered, with laser beaming looking like the better option.

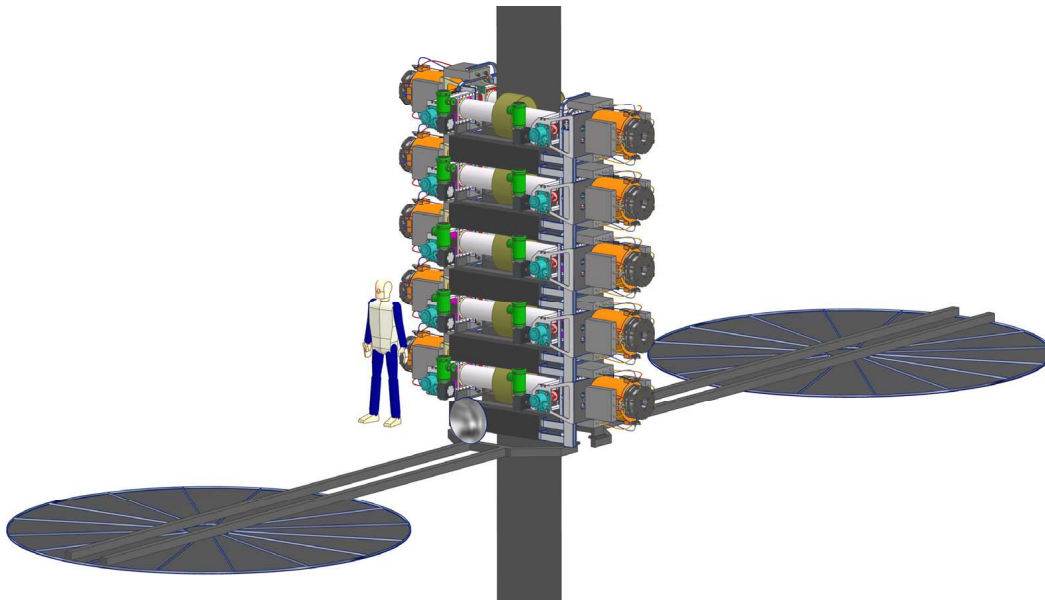


Figure 3: Conceptual design of a 20-ton climber capable of a 10-ton payload.

2.3 Tether Dynamics

The tether will be stretched taut between the Earth port and the apex anchor at 100,000 km. It will behave like a vibrating string with oscillations driven by climber motion, atmospheric effects such as wind, electromagnetic forces from the ionosphere and solar wind, as well as lunar and solar gravity. These oscillations will be longitudinal, transverse and torsional, making the full motion rather complex. The accurate prediction of these motions is a design and operational requirement for the space elevator. In another ongoing ISEC study, the software necessary to make the predictions and to visualize them is being designed. Digital twin technology is envisaged for feeding the expected motions to actuators on the tether and for sending back actual motions to correct the software predictions.

2.4 Architecture

The architecture is the overall design of the space elevator transportation infrastructure, including any number of individual space elevators, Earth ports, GEO and apex anchor stations. Over the years, it has

evolved from a single tether to the present Galactic Harbour⁶, consisting of three sets of twin tethers placed equidistantly along the equator. This design is easily scaled up to match perceived large tonnage demands for various exploration and space settlement missions.

An important aspect of the architecture is its accommodation of dual space access. Space elevators are vastly more efficient than rockets, but they are slow and more suited to large cargoes. Rockets will still be required for specific missions, such as transporting people or time-critical items, much like air travel today. Space elevators and rockets will be complementary.

3. Research

3.1 Studies

Each year since 2010, ISEC has completed at least one study focusing on issues of importance to space elevator development. A study runs for at least a year and consists of in-depth research into such technical topics as the effects of space debris, Earth port design, apex anchor function, climber design and system architecture. All studies are posted for free access on the ISEC website <https://www.isec.org/studies>. Studies now in progress deal with how to power the climber and the development of a suite of simulation and visualization software. Study participation is open to anyone who has an interest in the topic.

3.2 Support of Laboratory and Engineering Development

As mentioned above, two critical technologies need development: tether materials and climber design. While ISEC itself has no laboratory space or manufacturing plant, it takes part in and encourages such efforts. Several industry and university groups around the world are developing strong materials and the processes to manufacture them at a high rate. In some cases ISEC members have a stake in these companies or consult on development, pointing out the physical requirements of the materials and suggesting improvements in the manufacturing process.

Climber development is currently the province of space elevator competition groups (see below). It is hoped that these competitions will advance the state of the art, but clearly industrial involvement is required if full-scale climbers with appropriate powering methods are to emerge. ISEC contacts conventional elevator companies, encouraging them to get involved and pointing out that this technology can advance their own Earth-bound products.

4. Knowledge Base

The knowledge base for space elevators is expanding rapidly and there is a clear need to collect and curate this information so that it can be used to advance research and development. This service is provided on the website (www.isec.org), which contains all past ISEC studies, architecture notes, a video library, a history of space elevator development, an archive of past newsletters, a bibliography reference library and a publication repository containing hundreds of published articles on space-elevator and related topics.

ISEC researchers have published in academic journals such as *Acta Astronautica* and the *Journal of the British Interplanetary Society*. Space elevator articles also appear in *Ad Astra* and *Spaceflight* magazines.

5. Education and Outreach

ISEC either administers or supports programs designed to educate students at several levels, inform the general public and promote space elevators for space exploration and settlement.

5.1 Interns

ISEC interns have participated in space elevator research through the summer student program, which is aimed at university students. The student, once accepted, chooses a research topic and is assigned an ISEC researcher as mentor. Over the summer, research is done and a final report is submitted. There are also technical interns who take part in ongoing research. These interns are typically advanced undergraduates or graduate students.

5.2 ISEC Partners

Many space-related organizations have partnered with ISEC to promote their visions of space exploration and settlement, as they promote the ISEC vision of space elevators. These organizations include the National Space Society (nss.org), the British Interplanetary Society (bis-space.com), the World Space Elevator Competitions (wspec.org), the Mars Society (marsociety.org) and Space Renaissance International (spacerenaissance.space/sri/).



Figure 4. Space elevator climber team inspecting their equipment

5.3 Climber Competitions

A past and future thrust of ISEC is space elevator competitions. Designed to promote the technical development of the necessary technologies, these competitions focus on a particular aspect of the space elevator, such as the tether, climber or power transmission. Monetary prizes are often awarded when goals are achieved. ISEC currently partners with the World Space Elevator Competitions (WSPEC) and the Japan

Space Elevator Association (JSEA) to sponsor and support climber competitions around the world. Competing teams consist of high school students and professional engineers. Figure 4 shows one such team readying their climber for a test run.

6. Conclusion

Since its inception more than 20 years ago, the International Space Elevator Consortium has been promoting the development of space elevators and educating members of industry, academia and the general public in the transformational aspects of the space elevator. This transportation infrastructure will revolutionize space exploration and commerce, providing a low-cost alternative to rockets.

To these ends, ISEC has engaged in research activities to advance the state of the art in tether material production, climber design and overall space transportation architecture.

Three tether materials already exist which are strong enough to support themselves and payloads. It is now a matter of producing long lengths of multi-layer graphene laminates and scaling up production to produce large amounts of the material.

Recent tether climber designs indicate that modern day technology is nearly sufficient for building climbers capable of carrying 10-ton payloads. Rapidly advancing electric motor technology will soon fill that gap. Generating and transmitting power to the climber is now under study, with several existing technologies being evaluated.

ISEC supports laboratory efforts in both tether material development and climber technology. Space elevator competitions are one way of doing this, with high school, university and professional groups innovating climber and tether design to achieve preset goals.

ISEC has entered into partnerships with other space-related organizations in order to promote space settlement and spread the word about space elevators.

ACRONYMS

| Acronym | Description |
|---------|---|
| ISEC | International Space Elevator Consortium |
| CNT | Carbon Nanotube |
| SCG | Single Crystal Graphene |
| hBN | Hexagonal Boron Nitride |
| GSL | Graphene Super Laminate |
| WSPEC | World Space Elevator Competitions |
| JSEA | Japan Space Elevator Association |

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