## 1

#### Interp and violation: Affirmatives may not defend only specific instances of outer space appropriation by private entities as unjust.

#### "The" can either indicate a definite generic or definite description

Ojeda 91 [Almerindo E. Ojeda, PhD linguistics from UChicago, professor of linguistics at UC Davis. "Definite Descriptions and Definite Generics", Linguistics and Philosophy, Vol. 14, No. 4, pp. 367-397, Published August 1991, https://www.harvardlds.org/wp-content/uploads/2019/04/1-s2.0-S0010027718300313-main-3.pdf] HWIC

A definite noun phrase may be taken either as a definite description or as a definite generic. Thus, a noun phrase like the origin of the ballad may denote either the origin of an individual ballad we have been discussing, or else the origin of ballads in general as a literary species. In the first case, the ballad has been taken as a definite description; in the second, it has been taken as a definite generic.2 Notice that the ambiguity between definite descriptions and definite generics can be resolved in certain con texts. Thus, the definite noun phrase the computer is taken only as a definite description in (la), a statement about an individual computer; it is taken only as a definite generic in (lb), a statement about computers in general. Similarly, the definite noun phrase the dodo may be taken as a definite description in (2a) while it must be taken as a definite generic in (2b).3

(1)a. Turing repaired the computer.

b. Turing invented the computer.

(2)a. The dodo is dead.

b. The dodo is extinct.

#### Moral statements are generic normative principles – necessitates the generic interpretation

McDonald 09 [Hugh P. McDonald, professor of philosophy at the New York City College of Technology. "Principles: The Principles of Principles." The Pluralist, vol. 4, no. 3, [University of Illinois Press, Society for the Advancement of American Philosophy], 2009, pp. 98–126, https://www.jstor.org/stable/20708996] HWIC

"Principle" has a great many meanings: origin, beginning, cause, rule, axiom, and so on.5 However, we cannot assume any necessary relation of these meanings. They may be distinct meanings without relations. Neverthe less we can trace some common roots and thereby interconnections of the meanings. I will concentrate here on certain meanings relevant to the prin ciple of principles, that principles are actual. One meaning is that principles are the "ultimate source, origin, or cause of something" or the "originating or actuating agency or force." Principles are connected with the origin and cause of any "something." Moreover, principles may cause the actuality of the something. A second meaning of principles is that they regulate change, whether internally, as the "method of operation of a thing," or as an external cause. That is, principles are regulative, especially including rules for opera tions, involving changes. As rules, they are universal for a kind, although there may be exceptions to them in certain modes. A principle, then, is an originating rule that universally regulates the formation, operation, or other changes of any actuality, which as universal applies to that kind of thing. Machines may be built according to a principle and operate on the same or even a different principle. Ships presume the principle of floatation but may be built according to principles of woodworking or those of other materials. The principle can have different modes?whether necessary, as in logical inference; general, as in scientific laws; or actualization of possibilities, as in machines or as in moral principles that we follow, but could do otherwise.6 I will cover modes below.

Principles are also a cause as regulative, combining cause and rule. The principle can be external, as in a chemical catalyst; or internal, as in geneti cally caused changes.7 Both kinds of causes involve relations. Internal prin ciples exhibit "tendencies," to borrow the word used in the dictionary. They continue to operate across time. Actions that come under principles may be of kinds whose causes are separate in time, since we may cease an action for a time and then take it up again; while genetic characteristics are tenden cies whose causes are connected by reproduction. As causal, principles may be originary for a kind. Especially in new technologies, for example, flying machines, the principle that organisms could fly (birds, bats, and insects) preceded the invention of the technology, although the principles of aero dynamics were discovered later. However, flying utilized and actualized the latter principles. In this sense, principles can be constitutive rules as the origin of a kind, whether generic or specific.

External principles are regulative and not attributes. They regulate change, such that change is not chaotic. Principles are not bodies, objects, or entities but are the basis of the judgment or evaluation that the latter will persist, since they follow or are regulated by principles. Moreover, there is another sense in which principles are not attributes, since the relation of bodies, ob jects, or other terms for actualities implies a common principle, an identity that is regulated and constituted by the same actual principle. "Object" is a principle uniting instances normatively, for example, that solids persist unless acted upon by heat, etc.

Scientific, engineering, and practical laws are cases of principles. The "law of gravity" is the principle of gravity. Rules of "right conduct" also exhibit laws. Principles form an identity of different instances that fall under the law, whether generally or invariably. Laws and rules are regulative identities, applicable to different instances, and whether originary, constitutive, or ex ternally regulative. Voluntary adherence to a rule is bringing actions in line with a principle or enacting a principle.

Since principles are general, the statement of a principle includes an abstraction of some identity element of the instance. Principles, then, can constitute the elements in any instance insofar as there are identical ele ments, such as matter, species, and genera. This abstraction both identifies the instance as alike with other instances in some respect and differentiates it from those that do not exhibit the principle. The instance may contain several principles conjointly, matter, the state of the matter, function, aes thetic element, and many others. Thus principles connect like instances in a very complex set of relations. A diamond and a painting may share aesthetic qualities but their material, functional, and cultural principles may be quite different. Since identity and difference are correlative terms, every identity is also a difference and this principle applies to actual principles in the world, one principle of principles. To identify a rock of a certain type as consisting in certain chemical combinations connects it with that kind of mineral in general but also certain chemical elements in general, their physical proper ties (such as consisting of a certain atomic number of protons, electrons, and the like), and other principles. However, it also differentiates the rock from other types with their own specific principles, although some generic prin ciples may overlap, namely, the physical properties of all chemical elements as consisting in protons, electrons, and other principles of atoms. Principles then mark both a difference and an identity. The principles identify a distinc tion, but such identifications differentiate from other identifying principles. The wavelengths for green light are identical at different times of emission from the sun but are not identical with those for red.

#### Negate –

**1] Precision:**

**A] Topicality is a constitutive rule of the activity and a basic aff burden, they agreed to debate the topic when they came to the tournament**

**B] Jurisdiction -- you can’t vote affirmative if they haven’t affirmed**

**C] It’s the only stasis point we know before the round so it controls the internal link to engagement, and there’s no way to use ground if debaters aren’t prepared to defend it.**

**2] Limits: every specific instance or combination of instances of appropriation could be an aff like individual missions, programs or satellites, compounded by broad definitions of appropriation – unlimited topics incentivize obscure affs that negs won’t have prep on – limits are key to reciprocal prep burden. This topic already has very few neg generics and spec kills the innovation DA and space appropriation good – also means there is no universal DA to spec affs**

**Drop the debater – their abusive advocacy skewed our 1NC construction, allowing 1AR restart doesn't solve**

**Competing interps on T – topicality is a yes/no question, you can’t be reasonably topical, only competing interps create norms -- reasonability is arbitrary and invites judge intervention causing a race to the bottom of questionable argumentation**

## 2

#### CP text: Governments ought to

#### collaborate with private entities in lunar plant research and appropriation

#### institute law for property ownership in outer space

#### implement a phased approach to mining

#### Healthy competition between companies is a necessity for lunar research and new property ownership laws ensure sustainable and safe mining

Kornuta et. al 19

David Kornuta (project coordinator at United Launch Alliance) et. al (see [the publication](https://www.sciencedirect.com/science/article/abs/pii/S2352309318300099#!)); “Recommendations”, *Commercial lunar propellant architecture: A collaborative study of lunar propellant production*; *Aerospace Engineering*, University of Illinois; 2019; <https://experts.illinois.edu/en/publications/commercial-lunar-propellant-architecture-a-collaborative-study-of>; HW-EMJ

Recommendations146 For Government230 In order to establish a successful lunar propellant plant and fully realize all of its associated benefits requires private and government collaboration. The combined strengths of these players can be leveraged to create the healthiest and most sustainable space endeavor ever undertaken. A freely competed commercial propellant plant employing the US industrial base supported by PPP with Congress, NASA, DARPA, and other US government agencies represents humanities most capable partnership for propelling Earth based economies into the expanses of space. The following section will outline some of the fundamental roles that the US government should take to create this lasting space capability. The challenge is finding ways for the USG to encourage and stimulate the development of a commercial economy without managing it as a common economy. The role of NASA should include providing scientific exploration of the Permanently Shadowed Regions (PSR) of the Moon, assisting in developing early stage technologies and serving as an anchor customer of in-space propellant by proposing a price, quantity, and location of use. US government laboratories should assist in the development of required technology by providing support to commercial companies. Both NASA and other US government laboratories can also help facilitate demonstrations including fully Integrated System Tests (IST)s of a pilot plant. Finally, Congress should play a pivotal role in the creation of regulation and law that is enabling for a Commercial Lunar Propellant Architecture. All of these recommendations are discussed in more detail in the following sub-sections. Develop Precursor “Prospecting” Missions231 Prospecting (or scientific exploration) of the lunar polar regions is critical to building the foundation for a commercial lunar propellant plant. In addition to quantifying the abundance and concentration of the water ice deposits, there is a need to understand the environment as well. The designs of the extraction and transport systems are highly dependent on knowing what conditions actually exist at the mining site. The focal areas for precursor prospecting missions to explore should be: 1. Resource-related properties. We know from the Clementine, LCROSS, Chandrayaan-1, and LRO data232 that there is water ice in significant quantities in lunar polar craters. What is unknown is the distribution of water there, how deep it goes, and how well the regolith conducts heat (which would help with getting heat down to ice deeper in the regolith). 2. The surface environment. In order to transport equipment around to build the site, as well as transporting the product around, it is important to get more details on surface conditions, such as: how firm or soft is the surface; how easily is dust stirred up; what sizes of obstacles are likely to be encountered. 3. Stability. The surface of the Moon is not static. Micrometeorite impacts are frequent enough to create a small but measurable dust content233. Regolith on the sloping crater walls might collapse periodically similar to avalanches—especially with the increased vibrations coming from construction and transport activities. These conditions need to be assessed to design a safe facility, manage the dust problem, and include adequate protection from micrometeorite impact. The detailed recommendations for lunar volatile prospecting have been addressed in the CSM publication that was developed during the 2018 Space Resources Roundtable workshop. These recommendations can be found in the Lunar Polar Prospecting Workshop: Findings and Recommendations [172]234. Develop Prototype Pilot Plant on Earth235 The commercial lunar propellant plant will require a multi-billion-dollar capital investment. One-step in attracting this level of investment and proving the technology might be a smaller, lower-cost pilot plant on Earth. Given how a plant would have to be customized for lunar operations (modularization, weight reduction, safety, redundancy, and sparing, robotic assembly) a pilot plant would have a very positive impact on risk reduction and investor confidence. Most of the robotic operations could be demonstrated on Earth. Once the properties of the resource on the Moon were measured, extraction operations could be performed separately in a cryogenic vacuum chamber. It might also be desirable to install a pilot plant on the Moon itself, prior to starting construction of the industrial-scale commercial production facility. Institute Public Private Partnership236 We believe the establishment of a lunar ice mining operation is a great opportunity for a PPP. As was the case with NASA’s Commercial Orbital Transportation Services (COTS) program, all the elements for success are present. "Significant cost reductions from the norm of cost-plus contracting are possible for new space system elements in NASA’s exploration scenarios. ... There is no basis to conclude that public private partnerships end at low Earth orbit, prohibited or incapable of going beyond that point to deep space, the Moon or Mars." [173]237 First is a legitimate government need for the service. As stated earlier, NASA’s program to return to the Moon as well as operate in cislunar space assembling Mars exploration vehicles will benefit tremendously by the availability of low cost propellant on the Moon. As described in the Demand section, propellant purchased on the lunar surface represents a tremendous savings compared to bringing it from Earth. In addition, NASA will need oxygen and purified water, both products of the mining operation. Second is a defined commercial market for the product. As shown earlier, the commercial GEO satellite industry may drive the purchase of large quantities of propellant in LEO. If this demand is successfully met, other demands will emerge. For example, SpaceX has baselined refueling for its Big Falcon Rocket (BFR) rocket. Though the BFR uses methane fuel, LO2 represents a large fraction of its propellant mass. Blue Origin is also interested in refueling both its third stage and Blue Moon lander use LO2/LH2 propellants. With these two ingredients, the PPP can be structured as a fixed NASA investment into a commercially led mining operation development with a NASA commitment to purchase commodities in some amount. By specifying a price and quantity guaranteeing propellant purchases on the lunar surface, the wheels of American innovation and creativity can be set in motion to create capabilities NASA could not afford on its own. Capabilities that will underwrite a massive expansion of the human species into an entirely new environment. Annually increasing the price until the market responds with the needed capability is one method that could be used to overcome unseen difficulties along the way. To avoid picking winners and let the free market work more efficiently, it might be sufficient for NASA to commit to buy commodities (without investment) to stimulate the private sector to make the investment on its own. Many of these ideas have been discussed extensively. See, for example, the Lunar COTS proposal from [174]238 Promote Healthy Competition239 Though there are many positive impacts to the efficiency, cost reduction, and growth of a freely competed market, there can also be destructive effects depending on the diversity and abundance of customers. Historically, in cases where there is a single high stakes, high value customer to be won, fierce competition can evolve that sometimes hinders the growth of an economic ecosystem. Table 25 [152] depicts the differences between healthy competition (cooperative challenges) and cutthroat competition (competitive challenges). Although either of these approaches can be pursued within a privately competed lunar mine, healthy competition can be encouraged and established early on if the initial government customer strategically structures their propellant procurement process. Examples from other industries show the benefits of openness and information sharing. One positive example is the microwave communications industry. Microwave conferences began to be held in 1953, with competitors sharing the results of their research and collaborative discussions of new trends and developments. As a result, microwave transmission was the dominant form of high-data-rate communications for decades. For lunar propellant production, it is also true that the benefits of a collaborative and healthily competed commercial capability substantially outweighs an approach that is dominated by a single “winner”. Multiple vendors can increase the likelihood of a robust and reliable future supply chain that funds continuous innovation and capacity enhancement. Technological and operational capabilities can also benefit from the diversity of approaches a competitive ecosystem can draw. “Jeff Bezos, founder of Blue Origin and Amazon, comments that…competition should not be cutthroat to determine future monopoly…but creating an ecosystem for other entrepreneurs to thrive upon.” [142]240 Early on, healthy competition can be promoted through the purchasing strategy of the government customers described in the Lunar Surface and EML1 Customers section. The total demand proposed by these initial government customers should be divided among multiple commercial providers. Although this may make it more challenging to close the business case for these early companies, it will encourage them to develop even more lightweight, efficient, and creative solutions. In addition, it will stimulate the establishment of multiple providers that will pursue and cultivate new customers and uses for their products. Once additional customers, both government and commercial, are established, free market competition will continue to evolve with the lunar propellant industry. Facilitate Technology Development241 Various US Government laboratories have technologies that would be very useful in the commercial lunar propellant plant. These technologies could augment the development efforts within US aerospace companies. Partnerships with the US Government or its departments could accelerate the plant design. Some examples of applicable efforts: Air Force Research Laboratory: modular and “plug-and-play” satellite design Naval Research Laboratory: automated space robotic operations Jet Propulsion Laboratory: mobility on planetary surfaces Langley Research Center: in-space assembly techniques and hardware Marshall Space Flight Center: in-space manufacturing Some cooperative efforts between government and industry have resulted in additional capabilities that could be used. NASA’s Tipping Point program has invested in three efforts that could provide robotic assembly and construction capabilities (see the Lunar Surface Construction, Maintenance, and Repair section of this paper). DARPA’s RSGS program242 is developing autonomous failure response algorithms that could be adapted for use during facility construction and operation. In addition, the following technology areas identified in this paper would greatly benefit from government support: Volatile sublimation and capture in a vacuum High efficiency electrolysis Improved cryogenic management systems for in-space storage Ultralight, high efficiency solar panel masts Ultralight deployable solar reflectors Microwave and laser power beaming MW class space rated fission reactors Extreme cold and dust tolerant robotic actuators/components Autonomous control systems and machine learning In-space rendezvous, grappling, and propellant transfer Lunar communications architecture Refuelable, large, LO2/LH2 autonomous lunar landers Refuelable LO2/LH2 in-space transport Propellantless ascent options from the lunar surface Aerobraking and aerocapture in Earth’s atmosphere Institute Law for Property Ownership243 Because legal certainty allows a private entity the ability to know its costs and its potential return on investment, to attract investors, and to plan, U.S. recognition of a private entity’s property interests would advance exploration, investment, and U.S. leadership. Congress should consider codifying the principles of adverse possession as a means of ensuring legal certainty. Typically, adverse possession principles provide an analytical tool for figuring out if a person occupying someone else’s land should be allowed to take it from the original owner. However, some of the elements may be useful for robotic lunar mining as well. For example, Congress could enact legislation recognizing that a company’s human or robotic presence and control over a particular portion of terrain if the presence and control was continuous, open and notorious, actual, and exclusive for three years (or some other number), meant the company was recognized as the owner of the land. This particular proposal would require more analysis to flesh it out fully, and to review such historical analogs at the U.S. 19th century Homesteading and Mining Acts. For Private Sector244 The US industrial base is fully capable of tackling the technical challenges of a lunar propellant plant. In addition, a free market strategy for implementing this capability is critical to its longevity. Private organizations need to establish sustainable business models in order to maintain operations. Costs and commodity prices are bound by investors’ and customers’ availability and willingness to pay. Stakeholders in private enterprise hold companies accountable to generate revenue and produce returns while maintaining competitive edge. Therefore, it is recommended that this effort have significant private sector involvement and investment to ensure the sustained interest and active business development required at the foundation of an entirely new industry with government creating the environment where commercial entities can flourish. The following sections will outline recommendations to the private sector concerning leadership, competition, investment, and participation in the development of space law. Establish Leadership within the Private Sector245 The development and implementation of a commercial lunar propellant plant is a long-term investment strategy with incredible growth potential. As described throughout this study, the hardware solutions are well on their way to maturity. However, these hardware solutions are being developed by a multitude of companies for a variety of applications. It is only through the vision of the commercial lunar propellant plant that they are currently stitched together. To ensure that the development and implementation of this system is successful, it is necessary for leadership and organization of the many constituent parts of the architecture. It is highly recommended that this leadership be established within the private sector to maintain competitive, innovative, profit generating solutions throughout all phases of development. To reap the benefits of free market competition, multiple companies should be encouraged to take on the role of system integrators for competing lunar propellant mines. These private entities may or may not exist today but are necessary to administrate the many subcontractors similar to those identified in this study. In addition, the administrating companies would interface with investment firms, government agencies, and international organizations to generate funding, facilitate technology development, and establish the customer base required to close the business case. In order for these “Commercial Lunar Propellant Companies” to be successful, government support would also be crucial. To encourage and stimulate these privatized activities, the government should incorporate the operation into future space architectures, continue to fund development of applicable technologies, implement the legal framework to support commercial lunar activity, and establish a baseline lunar propellant demand and price as the anchor customer. This relationship was described in detail in the For Government section above. With a foundation in the free market, and with continued support from NASA and the US government, the commercial lunar propellant plants will establish the first permanent foothold for US economic opportunities on the Moon. Strategize for Investment Appeal246 The following sections discusses several strategic recommendations that an emerging commercial lunar mining company should utilize to better posture themselves for investment appeal. These strategies include high fidelity financial modeling, establishing insurability, diversifying applications, and incremental deployment. In addition to promoting investment appeal, these strategies are critical steps towards the realization of this emergent industry. A third party economic study of the commercial lunar propellant plant is essential to proving financial feasibility to the investment community and should be created. A high fidelity financial model contracted to an unbiased, reputable institution would be ideal. Within the high fidelity model, detailed inputs from the constituent companies should be stitched together. This data should include detailed cost, scheduling, and financial information provided for unbiased review and incorporation into the model. The model should treat each element of the lunar propellant plant as a subcontracted item that would be provided by the most capable companies. This high fidelity economic model will be a major element in communicating the investment value of the commercial lunar propellant plant as an integrated system. There is a close relationship between the willingness of investors to contribute to product development and the assessments of insurance underwriters. Investors will generally favor opportunities that are judged insurable. An early dialogue with the insurance underwriting community will be beneficial in the system design process. For example, understanding what are considered the highest consequence failures by the insurers will assist the designers in including the appropriate amounts of redundancy and the selection of components that meet the required standards. It is easier to attract investment to technology development for a mining enterprise if those technologies are not unique to that enterprise. The development program should emphasize the use of technologies that will have multiple applications. For example, space robotics can be used in markets other than lunar propellant—servicing of orbiting satellites, construction of large space structures, and in-space manufacturing. Developing technologies that can also be applied to terrestrial operations opens up an even greater variety of markets. Examples of applicable terrestrial markets include uses in deep-sea resource exploration, remote research, mining, and military operations, as well as the automation of complex industrial processes. Investors are more willing to fund technology development if they can see multiple avenues for return on their investment. Investment is likely to be attracted incrementally as the production capability gains in maturity. A terrestrial demonstration facility will show that the selected technologies can work together. Building and operating a demonstration or pilot plant (as describe in the Develop Prototype Pilot Plant section), will be key to raising confidence by proofing the system. A pilot plant on the Moon could also be important to attract investment, with the additional attraction that it would have some revenue generation capability, although less than the full-scale plant. Promote Investment Opportunities247 Akin to early investments in internet startups in the 1990’s, the emerging space economy offers high reward investments. With a multitude of different systems and services necessary for the lunar propellant production plant, there is substantial opportunity for investment. Dependent on investment timeline, acceptable risk, and desired company profile, an investor can choose the type of venture that will best suit them in this emerging space operation. Among the potential suppliers of the hardware required for the lunar propellant architecture, there is a wide variety of company maturity, size, and ambition. To simplify, these variations can be classified into four categories of investment opportunity. These categories are described below in order of least risk to highest risk. The first category consists of the legacy companies with current operations and mature technologies in the space sector. These companies have been established for over 20 years and usually have business operations in a variety of different fields. Companies in this stage are relatively low risk investments, but many are publicly traded companies with lower potential rewards from the growth of the space economy on a per shareholder basis. The second category consists of space companies recently founded yet mature with focused operations solely on the space economy, such as ULA, SpaceX or Blue Origin. These companies have established their technologies and have proven flight systems which lowers the potential risk for investors, while still allowing for larger potential rewards in the future than legacy companies. The third category is established startups. Companies that fall into this category usually have some established space technologies developed, well-defined business plans, and a strong core team in place. Not all of these companies have substantial investment yet. These companies are usually looking to move past the design phase, develop or further prototypes, or develop complementary technologies. This is a higher risk investment opportunity than the first two, but there are substantially large potential rewards for successful investments. Companies in this stage include Made In Space, Ispace, Astrobotic, NanoRacks, Masten Space Systems, and Lunar Outpost. The fourth opportunity to invest is in seed stage companies. There are many companies in this category and differentiating the good investments from the bad can take some work. Investors should look for the companies that have technically feasible ideas, strong teams to develop the needed technology, and fleshed out business plans. While not always the case, successful investments in early stage companies can reap higher rewards in the future. In an effort to provide a survey of how feasible ISRU on the Moon is, the CisLunar Marketplace Workshops have compiled a substantial database of enabling technologies and their current TRL. Augmented by industry and expert input, that database is the foundation of this study and ongoing discussions. As described in this study, the technologies necessary for lunar propellant production are currently developed or in development. This bolsters the investment prospects for all four stages of space companies. Today, the technologies needed for space resource utilization with low TRL provide excellent opportunity for investment. Given the high maturity of complementary technologies, the support of visionary investors, focus from established and well-respected companies, and talented young startups, it is our recommendation that investment opportunities into space resources and supporting infrastructure be viewed as promising and worth the risk. Because lunar propellant production is equally valuable as a monetary or capability investment, it is equally valuable to private or government investors as well. The companies that succeed in this venture will not only help shape the space economy but also advance space exploration while improving life here on Earth for generations to come, and potentially reap substantial returns. Active Role in Space Law248 Companies intending to extract space resources from the Moon or any other celestial body will need legal certainty that: They will have exclusive rights over a certain surface area of a celestial body where the resources extraction will take place Their operations will be protected from interference from competing companies They will have ownership rights over any extracted resources Since Article II of the Outer Space Treaty is broadly seen as prohibiting ownership rights (whether sovereign or private ownership rights), mining companies should be prepared to work with international organizations (such as the Hague Working Group on Space Resources). These organizations are currently seeking to formulate a method of providing companies with exclusive mining rights (which could be something less than property rights). Regarding non-interference with existing mining operations, existing international law already contains a requirement that space operators carry out their activities with “due regard” for the activity of others. However, international organizations are similarly occupied with creating a clearer international understanding of how interference can be best avoided. Industry input is critical as these details are worked out. With respect to the ownership of extracted resources, international law is rather clear that the mining company may assert such ownership rights. This interpretation of international law has been bolstered by domestic legislation in both the United States and Luxembourg. That said, companies should continue to monitor and be involved in any new legal developments on this topic. Technical249 The concept for commercial propellant production and distribution we have described in this paper is based on the adaptation of existing technologies—hardware, software, and operational concepts. The basic science of extraction, processing, transport, storage, and delivery systems exist. Their application to a low gravity, cold lunar crater environment using only robotics for maintenance is the great challenge. Technology development effort for the project should follow three tracks: Detailed modular design concepts for extraction and transport, based on information gained from precursor prospecting and environmental characterization missions Detailed modular concepts for power, processing, storage and delivery, that modify terrestrial system components for space flight and the lunar environment Algorithms and software that automate all phases of the project The “modular” requirement for system parts comes from the need to assemble, maintain and repair everything using robots. Modularity simplifies robotic hardware and software, and it makes parts storage and delivery much more flexible. Leverage Existing Systems250 The lunar propellant plant is similar in many ways to chemical plants on Earth. All such plants have chambers where the essential chemistry takes place; tanks for holding feedstock, intermediate and final products; plumbing and vehicles for moving products around the facility; power supplies and distribution; and control systems that automate most of the processes and actuate safety features. To re-engineer a terrestrial chemical plant for the lunar propellant application, major tasks will include: Modularization. Chemical plants are often highly integrated, with large components weighing several tons. A lunar plant design will need to be broken into smaller parts that can be robotically moved from the landing site to the installation site, and robotically assembled with ease. Weight reduction. Builders of terrestrial plants are relatively unconstrained by the masses of components, other than limits of available lifting gear. Because launch and space transport are highly weight-constrained, designers should consider options such as operation at lower pressures (which reduces the weight of chambers and pipes), even if some reduction in efficiency would occur. Safety in design. Some properties of the lunar environment pose hazards to which terrestrial plants are not exposed. Most important are radiation and micrometeorites. Plant systems must be tolerant to these hazard sources. Redundancy and sparing. Investors, insurers, and customers will insist on a high level of assurance that production will be continuous and reliable. Repair times will be much more dependent on redundancy and sparing than for terrestrial plants. Having to wait for component delivery from Earth to restore production after a failure will be unattractive to investors. On-site spares, redundant components, automated responses, and robotic services will be key. Apply Automation251 Robotic operations follow one of four general modes: scripted, teleoperated, supervised autonomy and full autonomy. Choice of which mode to use depends on the availability of information (e.g. positions and orientation of components) and connectivity. Design of the lunar propellant installation will assign these modes to the various robotic operations during site preparation, construction, operation, maintenance, and repair. Fully autonomous operation sounds difficult, but it has been demonstrated in space252. Other automation features that need to be included in the design will be: Fault detection, identification and response. Robots will encounter components that are not in the nominal configuration (e.g. bent connectors). They themselves will also experience failures (e.g. electrical shorts, suspension problems). If such anomalies can be resolved without involving humans on Earth, the efficiency will be greatly improved. Process monitoring and control. Terrestrial chemical plants often include human oversight, both in control centers and around the plant. Lunar plant control must be completely automated, because the facility will have only intermittent connectivity with humans on Earth or at NRHO (which will only be intermittently occupied in any event). Without fully automated operation, failures that occur at times without human oversight could propagate and have serious consequences. Establish Standards253 Each subsystem of the lunar extraction and production facility will have to interface with other systems throughout its life cycle. These interfaces should be standardized in order to reduce costs (Standards as Cost Savings) and improve efficiency. The overall complexity of this facility is comparable to that of the ISS. Even on ISS, examples such as NASA’s International Docking System (IDS) demonstrate the necessity of standardization in space. A list of interfaces that must be considered in the design of the lunar propellant plant includes:  Pre-launch interfaces with ground support equipment (mechanical and electrical)  Launch vehicle interface (launch restraints, restraint release power, telemetry)  Lunar lander interface (at least mechanical)  Interface with transport robot (at least mechanical, probably also power for survival heat)  Interfaces with other facility subsystems (mechanical, power, control, telemetry, fluids, thermal) A design challenge for most components will be the wide variety of environments that they experience—launch vibrations, landing forces, lunar day and night, abrasion from regolith, transport by robot and in some cases the extreme cold of the shadowed craters. The interface designs will be driven by the need to accommodate all of these environments. Propellant transfer interfaces need multiple fluid paths, mechanical, power, data and command interfaces as well. Any space vehicle receiving or transferring lunar propellant will need a fuel and an oxidizer interface for primary and attitude control propellants. There may also be a need to exchange ullage as well as propellant. As described in the Rendezvous and Capture section, Altius Space Machines has a Phase II SBIR to develop a cryogenic transfer interface. Implementing these types of interfaces as standards is crucial to efficient implementation of the lunar propellant architecture. The benefit of standardizing these interfaces includes simplicity of planning, reduced cost, and enhanced reliability. Relevant research is being performed by the DLR for modular design of satellites. In a project called Intelligent Building Blocks for On-Orbit Satellite Servicing and Assembly (iBOSS)254, an Intelligent Space System Interface has been developed. Potentially, generalizing such promising interface designs may be greatly beneficial in engineering the assembly of the lunar plant. However, there is a danger to overly specific interface standardization, namely the potential inability to accommodate new features. An insight may be drawn from the 120V wall plug. It is a standardized design, but does not greatly constrain the equipment that it powers. “Flexible standardization” is the ideal approach for a system of the complexity of the lunar propellant plant. Path Forward255 A commercial lunar propellant system will be a vast undertaking. A phased approach is recommended, each phase serving to increase maturity of the technologies, attract increased levels of investment, and develop markets and customers. An example of a phased development program is: Phase 0: Establish business viability. In order to secure adequate funding, the following items must be completed prior to, or in parallel with, to the subsequent phases: NASA and others propose propellant demand, price, and location of use as customer base Prospecting and science exploration of lunar polar regions Improved space law to facilitate commercial utilization of lunar resources Commercial lunar propellant companies form for managing the many subcontractors Third party high fidelity financial models Secure investment for technology development and maturity Technology applied to terrestrial markets to generate revenue Implementation of international lunar communications architecture Phase I: Individual technology demonstrations. Organizations will continue to raise the TRL of critical hardware elements through technology demonstrations. This phase can be greatly accelerated with PPP: Demonstrating sublimation from regolith simulant Robotic demonstrations of plant assembly techniques Reusable lunar lander development Hydrogen/oxygen-fueled vehicles for operations in Earth orbit, such as LEO-to-GEO tugs Additional technology demonstrations outlined within previous sections of this study Phase II: Subscale terrestrial demonstration plant. Although conducted on Earth, elements of this IST could be conducted in simulated Permanently Shadowed Regions (PSR) environments including: Assembly demonstrations of all components of the plant Robotic operations in cryogenic conditions Efficient subscale processing plant with lightweight components System interface validation Vacuum chamber IST with cold wall for end-to-end system verification Phase III: Subscale lunar production plant. The following activities will boost the TRL of the integrated lunar propellant production plant to 9: May be scaled to fit on a single launch vehicle for delivery to PSR Designed for limited operations or production Demonstrates collection, transport, processing, and storage of cryogenic propellant Propellant produced can support robotic exploration and sample return missions Becomes seed for full-scale production plant Phase IV: Full-scale commercial lunar production facility. Initiates US industrialization on another terrestrial body. Establishes sustained presence on the Moon. Technology has been fully vetted Customer base is well established Required resource mapping complete Investment has been secured The legal framework is in place All infrastructure is delivered to the lunar surface Full-scale propellant production in support of space missions underway Transport from lunar surface to space is in place Phase V: Iterative system enhancement. In the decades following the establishment of the lunar propellant plant, new technologies will be integrated into the system to improve performance, decrease operating costs, and enable effective utilization of its products. Utilization of lunar propellant to expand the facility (Bootstrapping Deployment section) Installation of tracks and roadways for robotic operations (Surface Mobility section) Propellantless ascent systems for delivery to orbit (Propellantless Ascent section) Efficient LEO delivery (Aerobraking/Aerocapture for LEO Delivery section) Unforeseen new technologies driven by healthy commercial competition to innovate Phase ∞: Well established lunar propellant industry. The Moon and its resources become a gateway to the solar system. Its resources are used for space exploration as well as to benefit life on Earth. Robust and highly scalable space economy (Enabled Industries section) Improved scientific understanding of the Moon and beyond (Science Benefits sections) Enables solutions to Earth’s energy crisis (Energy section) Supports space habitation (Supporting Human Settlement and Existential Threats sections) Is the first step in humanity’s journey through the cosmos (Grand Science and Exploration) Establishing a commercial lunar propellant plant is fundamental to the exponential growth and prosperity of humankind. This effort requires industry, government, and academic collaboration on a scale more extensive than humanity’s greatest historic engineering achievements. Like those achievements, the challenge is great but the value is even greater. Producing far more than just near term economic gains, this Commercial Lunar Propellant Architecture enables entirely new opportunities for human civilization.

## 3

#### Space-for-space economy is beginning to develop now because of private enterprise in space

Weinzierl and Sarang 21 (Matt, PhD in Economics Harvard University, Joseph and Jacqueline Elbling Professor of Business Administration at HBS and a Research Associate at the National Bureau of Economic Research, and Mehak, Research Associate at Harvard Business School and the Lunar Exploration Projects Lead for the MIT Space Exploration Initiative, Harvard Business Review, "The Commercial Space Age is Here," 2/12, <https://hbr.org/2021/02/the-commercial-space-age-is-here>)

In 2019, 95% of the estimated $366 billion in revenue earned in the space sector was from the space-for-earth economy: that is, goods or services produced in space for use on earth. The space-for-earth economy includes telecommunications and internet infrastructure, earth observation capabilities, national security satellites, and more. This economy is booming, and though research shows that it faces the challenges of overcrowding and monopolization that tend to arise whenever companies compete for a scarce natural resource, projections for its future are optimistic. Decreasing costs for launch and space hardware in general have enticed new entrants into this market, and companies in a variety of industries have already begun leveraging satellite technology and access to space to drive innovation and efficiency in their earthbound products and services. In contrast, the space-for-space economy — that is, goods and services produced in space for use in space, such as mining the Moon or asteroids for material with which to construct in-space habitats or supply refueling depots — has struggled to get off the ground. As far back as the 1970s, research commissioned by NASA predicted the rise of a space-based economy that would supply the demands of hundreds, thousands, even millions of humans living in space, dwarfing the space-for-earth economy (and, eventually, the entire terrestrial economy as well). The realization of such a vision would change how all of us do business, live our lives, and govern our societies — but to date, we’ve never even had more than 13 people in space at one time, leaving that dream as little more than science fiction. Today, however, there is reason to think that we may finally be reaching the first stages of a true space-for-space economy. SpaceX’s recent achievements (in cooperation with NASA), as well as upcoming efforts by Boeing, Blue Origin, and Virgin Galactic to put people in space sustainably and at scale, mark the opening of a new chapter of spaceflight led by private firms. These firms have both the intention and capability to bring private citizens to space as passengers, tourists, and — eventually — settlers, opening the door for businesses to start meeting the demand those people create over the next several decades with an array of space-for-space goods and services.

#### Asteroid mining requiresprivate moon basing – obviously public moon basing doesn’t go to make an economy

Weinzierl and Sarang 21 (Matt, PhD in Economics Harvard University, Joseph and Jacqueline Elbling Professor of Business Administration at HBS and a Research Associate at the National Bureau of Economic Research, and Mehak, Research Associate at Harvard Business School and the Lunar Exploration Projects Lead for the MIT Space Exploration Initiative, Harvard Business Review, "The Commercial Space Age is Here," 2/12, <https://hbr.org/2021/02/the-commercial-space-age-is-here>)

To be sure, people have dreamt of using the vacuum and weightlessness of space to source or make things that cannot be made on earth for half a century, and time and again the business case has failed to pan out. Skepticism is natural. Those failures, however, have been in space-for-earth applications. For example, two startups of the 2010s, Planetary Resources, Inc. and Deep Space Industries, recognized the potential of space mining early on. For both companies, however, the lack of a space-for-space economy meant that their near-term survival depended on selling mined material — precious metals or rare elements — to earthbound customers. When it became clear that demand was insufficient to justify the high costs, funding dried up, and both companies pivoted to other ventures. These were failures of space-for-earth business models — but the demand for in-space mining of raw building material, metals, and water will be enormous once humans are living in space (and are therefore far cheaper to supply). In other words, when people are living and working in space, we are likely to look back on these early asteroid mining companies less as failures and more as simply ahead of their time.

#### Mining solves extinction from scarcity.

Pelton 17—(Director Emeritus of the Space and Advanced Communications Research Institute at George Washington University, PHD in IR from Georgetown).. Pelton, Joseph N. 2017. The New Gold Rush: The Riches of Space Beckon! Springer. Accessed 8/30/19.

Are We Humans Doomed to Extinction? What will we do when Earth’s resources are used up by humanity? The world is now hugely over populated, with billions and billions crammed into our overcrowded cities. By 2050, we may be 9 billion strong, and by 2100 well over 11 billion people on Planet Earth. Some at the United Nations say we might even be an amazing 12 billion crawling around this small globe. And over 80 % of us will be living in congested cities. These cities will be ever more vulnerable to terrorist attack, natural disaster, and other plights that come with overcrowding and a dearth of jobs that will be fueled by rapid automation and the rise of artifi cial intelligence across the global economy. We are already rapidly running out of water and minerals. Climate change is threatening our very existence. Political leaders and even the Pope have cautioned us against inaction. Perhaps the naysayers are right. All humanity is at tremendous risk. Is there no hope for the future? This book is about hope. We think that there is literally heavenly hope for humanity. But we are not talking here about divine intervention. We are envisioning a new space economy that recognizes that there is more water in the skies that all our oceans. Th ere is a new wealth of natural resources and clean energy in the reaches of outer space—more than most of us could ever dream possible. There are those that say why waste money on outer space when we have severe problems here at home? Going into space is not a waste of money. It is our future. It is our hope for new jobs and resources. The great challenge of our times is to reverse public thinking to see space not as a resource drain but as the doorway to opportunity. The new space frontier can literally open up a “gold rush in the skies.” In brief, we think there is new hope for humanity. We see a new a pathway to the future via new ventures in space. For too long, space programs have been seen as a money pit. In the process, we have overlooked the great abundance available to us in the skies above. It is important to recognize there is already the beginning of a new gold rush in space—a pathway to astral abundance. “New Space” is a term increasingly used to describe radical new commercial space initiatives—many of which have come from Silicon Valley and often with backing from the group of entrepreneurs known popularly as the “space billionaires.” New space is revolutionizing the space industry with lower cost space transportation and space systems that represent significant cost savings and new technological breakthroughs. “New Commercial Space” and the “New Space Economy” represent more than a new way of looking at outer space. These new pathways to the stars could prove vital to human survival. If one does not believe in spending money to probe the mysteries of the universe then perhaps we can try what might be called “calibrated greed” on for size. One only needs to go to a cubesat workshop, or to Silicon Valley or one of many conferences like the “Disrupt Space” event in Bremen, Germany, held in April 2016 to recognize that entrepreneurial New Space initiatives are changing everything [ 1 ]. In fact, the very nature and dimensions of what outer space activities are today have changed forever. It is no longer your grandfather’s concept of outer space that was once dominated by the big national space agencies. The entrepreneurs are taking over. The hopeful statements in this book and the hard economic and technical data that backs them up are more than a minority opinion. It is a topic of growing interest at the World Economic Forum, where business and political heavyweights meet in Davos, Switzerland, to discuss how to stimulate new patterns of global economic growth. It is even the growing view of a group that call themselves “space ethicists.” Here is how Christopher J. Newman, at the University of Sunderland in the United Kingdom has put it: Space ethicists have offered the view that space exploration is not only desirable; it is a duty that we, as a species, must undertake in order to secure the survival of humanity over the longer term. Expanding both the resource base and, eventually, the habitats available for humanity means that any expenditure on space exploration, far from being viewed as frivolous, can legitimately be rationalized as an ethical investment choice. (Newman) On the other hand there are space ethicists and space exobiologists who argue that humans have created ecological ruin on the planet—and now space debris is starting to pollute space. Th ese countervailing thoughts by the “no growth” camp of space ethicists say we have no right to colonize other planets or to mine the Moon and asteroids—or at least no right to do so until we can prove we can sustain life here on Earth for the longer term. However, for most who are planning for the new space economy the opinion of space philosophers doesn’t really fl oat their boat. Legislators, bankers, and aspiring space entrepreneurs are far more interested in the views of the super-rich capitalists called the space billionaires. A number of these billionaires and space executives have already put some very serious money into enterprises intent on creating a new pathway to the stars. No less than five billionaires with established space ventures—Elon Musk, Paul Allen, Jeff Bezos, Sir Richard Branson, and Robert Bigelow—have invested millions if not billions of dollars into commercializing space. They are developing new technologies and establishing space enterprises that can bring the wealth of outer space down to Earth. This is not a pipe dream, but will increasingly be the economic reality of the 2020s. These wealthy space entrepreneurs see major new economic opportunities. To them space represents the last great frontier for enterprising pioneers. Th us they see an ever-expanding space frontier that offers opportunities in low-cost space transportation, satellite solar power satellites to produce clean energy 24h a day, space mining, space manufacturing and production, and eventually space habitats and colonies as a trajectory to a better human future. Some even more visionary thinkers envision the possibility of terraforming Mars, or creating new structures in space to protect our planet from cosmic hazards and even raising Earth’s orbit to escape the rising heat levels of the Sun in millennia to come. Some, of course, will say this is sci-fi hogwash. It can’t be done. We say that this is what people would have said in 1900 about airplanes, rocket ships, cell phones and nuclear devices. The skeptics laughed at Columbus and his plan to sail across the oceans to discover new worlds. When Thomas Jefferson bought the Louisiana Purchase from France or Seward bought Alaska, there were plenty of naysayers that said such investment in the unknown was an extravagant waste of money. A healthy skepticism is useful and can play a role in economic and business success. Before one dismisses the idea of an impending major new space economy and a new gold rush, it might useful to see what has already transpired in space development in just the past five decades. The world’s first geosynchronous communications satellite had a throughput capability of about 500 kb / s. In contrast, today’s state of the art Viasat 2 —a half century later— has an impressive throughput of some 140 Gb/s. Th is means that the relative throughput is nearly 300,000 greater, while its lifetime is some ten times longer (Figs. 1.1 and 1.2 ). Each new generation of communications satellite has had more power, better antenna systems, improved pointing and stabilization, and an extended lifetime. And the capabilities represented by remote sensing satellites , meteorological satellites , and navigation and timing satellites have also expanded their capabilities and performance in an impressive manner. When satellite applications first started, the market was measured in millions of dollars. Today commercial satellite services exceed a quarter of a billion dollars. Vital services such as the Internet, aircraft traffi c control and management, international banking, search and rescue and much, much more depend on application satellites. Th ose that would doubt the importance of satellites to the global economy might wish to view on You Tube the video “If Th ere Were a Day Without Satellites?” [ 2 ]. Let’s check in on what some of those very rich and smart guys think about the new space economy and its potential. (We are sorry to say that so far there are no female space billionaires, but surely this, too, will come someday soon.) Of course this twenty-fi rst century breakthrough that we call the New Space economy will not come just from new space commerce. It will also come from the amazing new technologies here on Earth. Vital new terrestrial technologies will accompany this cosmic journey into tomorrow. Information technology, robotics, artificial intelligence and commercial space travel systems have now set us on a course to allow us humans to harvest the amazing riches in the skies—new natural resources, new energy, and even totally new ways of looking at the purpose of human existence. If we pursue this course steadfastly, it can be the beginning of a New Space renaissance. But if we don’t seek to realize our ultimate destiny in space, Homo sapiens can end up in the dustbin of history—just like literally millions of already failed species. In each and every one of the five mass extinction events that have occurred over the last 1.5 billion years on Earth, some 50–80 % of all species have gone the way of the T. Rex, the woolly mammoth, and the Dodo bird along with extinct ferns, grasses and cacti. On the other hand, the best days of the human race could be just beginning. If we are smart about how we go about discovering and using these riches in the skies and applying the best of our new technologies, it could be the start of a new beginning for humanity. Konstantin Tsiokovsky, the Russian astronautics pioneer, who fi rst conceived of practical designs for spaceships, famously said: “A planet is the cradle of mankind, but one cannot live in a cradle forever.” Well before Tsiokovsky another genius, Leonardo da Vinci, said, quite poetically: “Once you have tasted flight, you will forever walk the earth with your eyes turned skyward, for there you have been, and there you will always long to return.” The founder of the X-Prize and of Planetary Resources, Inc., Dr. Peter Diamandis, has much more brashly said much the same thing in quite diff erent words when he said: “The meek shall inherit the Earth. The rest of us will go to Mars.” The New Space Billionaires Peter Diamandis is not alone in his thinking. From the list of “visionaries” quoted earlier, Elon Musk, the founder of SpaceX; Sir Richard Branson, the founder of Virgin Galactic; and Paul Allen, the co-founder of Microsoft and the man who financed SpaceShipOne, the world’s first successful spaceplane have all said the future will include a vibrant new space economy. Th ey, and others, have said that we can, we should and we soon shall go into space and realize the bounty that it can offer to us. Th e New Space enterprise is today indeed being led by those so-called space billionaires , who have an exciting vision of the future. They and others in the commercial space economy believe that the exploitation of outer space may open up a new golden age of astral abundance. They see outer space as a new frontier that can be a great source of new materials, energy and various forms of new wealth that might even save us from excesses of the past. Th is gold rush in the skies represents a new beginning. We are not talking about expensive new space ventures funded by NASA or other space agencies in Europe, Japan, China or India. No, these eff orts which we and others call New Space are today being forged by imaginative and resourceful commercial entrepreneurs. Th ese twenty-fi rst century visionaries have the fortitude and zeal to look to the abundance above. New breakthroughs in technology and New Space enterprises may be able to create an “astral life raft” for humanity. Just as Columbus and the Vikings had the imaginative drive that led them to discover the riches of a new world, we now have a cadre of space billionaires that are now leading us into this New Space era of tomorrow. These bold leaders, such as Paul Allen and Sir Richard Branson, plus other space entrepreneurs including Jeff Bezos of Amazon and Blue Origin, and Robert Bigelow, Chairman of Budget Suites and Bigelow Aerospace, not only dream of their future in the space industry but also have billions of dollars in assets. These are the bright stars of an entirely new industry that are leading us into the age of New Space commerce. These space billionaires, each in their own way, are proponents of a new age of astral abundance. Each of them is launching new commercial space industries. They are literally transforming our vision of tomorrow. These new types of entrepreneurial aerospace companies—the New Space enterprises—give new hope and new promise of transforming our world as we know it today. The New Space Frontier What happens in space in the next few decades, plus corresponding new information technologies and advanced robotics, will change our world forever. These changes will redefi ne wealth, change our views of work and employment and upend almost everything we think we know about economics, wealth, jobs, and politics. Th ese changes are about truly disruptive technologies of the most fundamental kinds. If you thought the Internet, smart phones, and spandex were disruptive technologies, just hang on. You have not seen anything yet. In short, if you want to understand a transition more fundamental than the changes brought to the twentieth century world by computers, communications and the Internet, then read this book. There are truly riches in the skies. Near-Earth asteroids largely composed of platinum and rare earth metals have an incredible value. Helium-3 isotopes accessible in outer space could provide clean and abundant energy. There is far more water in outer space than is in our oceans. In the pages that follow we will explain the potential for a cosmic shift in our global economy, our ecology, and our commercial and legal systems. These can take place by the end of this century. And if these changes do not take place we will be in trouble. Our conventional petro-chemical energy systems will fail us economically and eventually blanket us with a hydrocarbon haze of smog that will threaten our health and our very survival. Our rare precious metals that we need for modern electronic appliances will skyrocket in price, and the struggle between “haves” and “have nots” will grow increasingly ugly. A lack of affordable and readily available water, natural resources, food, health care and medical supplies, plus systematic threats to urban security and systemic warfare are the alternatives to astral abundance. The choices between astral abundance and a downward spiral in global standards of living are stark. Within the next few decades these problems will be increasingly real. By then the world may almost be begging for new, out of- the-box thinking. International peace and security will be an indispensable prerequisite for exploitation of astral abundance, as will good government for all. No one nation can be rich and secure when everyone else is poor and insecure. In short, global space security and strategic space defense, mediated by global space agreements, are part of this new pathway to the future.

#### That’s key to satellite monitoring, resource management, agriculture, climate change monitoring, and space-based solar power development

Sommariva 20 (Andrea, Italian Institute for International Political Studies, "The Evolution of Space Economy: The Role of the Private Sector and the Challenges for Europe," 12/11, <https://www.ispionline.it/en/pubblicazione/evolution-space-economy-role-private-sector-and-challenges-europe-28604>)

The second factor focuses on spacecraft and space-access costs. NASA has moved from a government-run International Space Station access system to one where the transportation of goods and people relies on private companies, obviously under contract and control of NASA, thus eliminating the monopoly of Lockheed Martin and Boeing. As a result, significant progress has been made in the design and development of cost-effective launch vehicles. Currently, SpaceX has developed a system to reuse the first stage of rockets, which serves to give the initial thrust necessary to overcome Earth's atmosphere. Normally, after doing its job, the first stage came off and fell into the ocean as waste. SpaceX has successfully developed the recovery and reuse of the first stages of rockets, reducing the cost per kilogram of payload by more than 50 percent. These developments provide access to space for many small and medium-sized companies, as well as educational and research institutions. In the near future, the development of the satellite Internet will allow people and companies to connect wherever they are - an effective alternative when terrestrial networks are absent or of poor quality. In addition, satellite technology gives rise to a growing stream of uses, including transportation and logistics efficiency, natural resource management, precision agriculture, environment and climate change monitoring, and makes it a potential source of economic growth, social well-being, and sustainable development. As for the exploration programs, the return to the Moon is now days on the agendas of the major space agencies, such as NASA and ESA. Over the next ten to fifteen years, the use of space resources will be crucial for the success of expeditions to the Moon and other planets. The Moon's resources provide propellant for the in-orbit refueling of spacecraft, reducing their costs[1], and oxygen and water for support systems of the future space station around the Moon (the Gateway project). A new form of public-private partnership is rising, a partnership in which governments will provide initial support in the exploration and the advancement of critical technologies (telecommunications and Moon-Earth navigation), and in the construction of space infrastructure. NASA plans a first exploration mission at the South Pole of the Moon in 2024. The private sector would then take the lead in creating new markets and expanding the presence of humanity in space. SpaceX is developing a vehicle, Starship, for missions to the Moon and beyond. The Starship is a fully reusable launch vehicle. It consists of two stages, the booster and the spacecraft, which in November 2018 Elon Musk renamed Super Heavy and Starship respectively. The overall vehicle architecture includes both the launcher and the vehicle, as well as the infrastructure for the first and subsequent launches, and zero-gravity propellant transfer’s technology. The spacecraft alone is designed to be used, in a first phase, without a booster for both freight and passenger transport. In April 2020, NASA selected a modified version of the Starship as one of three landing systems for the Artemis Program. Moon mining will present also an opportunity to make space based solar power (SBSP) economically feasible. SBSP has been studied for decades. However, the costs of launching such large infrastructure from Earth to geosynchronous orbit (GEO) make these projects economically not feasible. At the SEE Lab-SDA Bocconi, we have initiated a study where the basic idea is to build the SBSP satellite with material from the Moon and to transfer the components to GEO where they would be assembled. Its costs are comparable to a large-scale nuclear power plant. If preliminary results are confirmed by the completion of the study, space based solar power can transform the energy markets of Earth[2], and can give an important contribution to the climate change’s mitigation.

#### SBSP is necessary to reduce emissions and solve climate change

Shtivelman 12 - J.D., Boston University School of Law [Aleksey, 2012, *B. U. J. SCI. & TECH. L. Vol. 18:435*, “SOLAR POWER SATELLITES: THE RIGHT TO A SPOT IN THE WORLD'S HIGHEST PARKING LOT”, Hein Online]

\*\*\*edited for gendered language

Rather than spending millions on land-based solar power projects, it would be much more profitable if these nations invested in SBSP satellites for two reasons. First, although SBSP satellites are much more expensive at the outset, the cost of initial investment is returned in a period of time comparable to what it would take to recoup the investment cost of a land-based solar farm. 113 Second, SBSP satellites generate about eight to ten times as much power as land-based solar farms."l 4 This means that after one and a half years, SBSP satellites would generate eight to ten times the revenue of a land-based solar farm. As a result, countries that currently rely on coal, nuclear or other types of non-clean, non-renewable energy may look to SBSP for their energy needs, and consequently generate a significant spike in demand for orbital locations on the GSO. This increased demand will raise two issues: (1) whether a GSO orbital slot can be owned, and, (2) if not, whether there is a way to allocate the right to access GSO orbital slots for a period of time. A viable legal framework could address both of these issues in a clear and precise manner. The ITU currently allocates slots for telecommunications satellites, but the increased demand for slots in GSO for SBSP satellites may force countries to reevaluate ITU's authority to regulate SBSP satellites.

1. An unsuccessful attempt to appropriate GSO slots

The ITU allocation is one way to solve the problem, but given the physical limitations of the GSO, there is an underlying conflict between the goals of fair and equitable access on one side and the GSO's efficient use on the other.' 5 The conflict arises when developed countries receive priority to access the GSO because they have the demand, infrastructure, and funding to put satellites into orbit, while developing countries without viable satellites also want access the GSO. 116 This a posteriori approach to GSO property rights favors those who are first to apply for frequency and orbital slots and protects those applicants from interference by later users."17 At the same time, developing countries do not favor such a "free-market-approach" to GSO access; on the contrary, they would like a multilateral approach that distributes access to the GSO equitably among all nations. 118 "As feared by the developing States, this a posteriori system [has] provided a few industrialized and rich States with the opportunity of temporarily unlimited use of registered frequencies and orbit positions."' "19 Developing countries feel that they should have equal access to these frequencies and orbital slots. 120 These countries have tried to gain leverage over the GSO resource by advocating for the creation of an administrative agency that would allocate a part of the GSO to each country. In 1976, eight developing countries above the equator claimed sovereign right over the parts of the GSO lying over their territories and called for the administration of the rest of the GSO. 12 ' The Declaration of the First Meeting of Equatorial Countries (the "Bogota Declaration") asserted that these countries had the right to parts of the GSO because the orbit should be considered part of the earth and not outer space. 22 These countries argued that the gravitational force that produces the GSO was defived from their land.' 23 Both developed and developing countries rejected the Bogota Declaration's arguments because its claims were weak: the gravity that produces the orbit (1) is produced by the entire earth, not just these eight nations, and (2) produces all orbits, not just the GSO.124 Another of the arguments in the Bogota Declaration was that there is no legally defined boundary as to where an atmosphere ends and space begins. 125 Furthermore, the Bogota Declaration declared that even the Outer Space Treaty, which provides the basic outline for the peaceful exploration and use of outer space, does not address the issue. 126 While there is no definition that all countries in the world accept regarding the boundary of space, the International Aeronautic Federation recognizes the Karman Line as the edge of the atmosphere and the beginning of space.' 27 The International Aeronautic Federation is a non-governmental organization founded in 1905, for the purpose of encouraging aeronautical and astronautical activities worldwide. 28 It has 100 member countries, including the United States, United Kingdom, Spain, Sweden, South Africa, Mongolia, Korea, Israel, Iran, as well as many others.1 29 For the preceding reasons, the International Aeronautic Federation portrays a widely held view concerning the definition of space. The Karman line is one hundred kilometers above sea level, and that is where the atmosphere becomes so thin that an airplane cannot fly and a spaceship is needed for flight.' 30 The GSO lies more than 35,000 kilometers above sea level, which is approximately 34,900 kilometers higher than the Karman line. Therefore, GSO is well above the demarcation of space that is internationally recognized. For this reason and others, most countries did not accept the Bogota Declaration. Accordingly, the Bogota Declaration was an unsuccessful attempt to appropriate GSO slots.

1. Space law must allow appropriation of space for the good of everyone

The Bogota Declaration was ultimately a failure because it violated internationally accepted principles. According to the Outer Space Treaty of 1967, GSO orbital positions and frequencies cannot be appropriated because no country can appropriate or own space. 31 Ninety-one states have signed this treaty, including the United States, the United Kingdom, Ukraine, Japan, Greece, Denmark, Spain, Uganda, Afghanistan, Iraq and many others. 32 The treaty specifies that outer space is the "province of mankind" and that all activity should be done for the benefit of all of humanity. 133 It would then seem that no country could have exclusive ownership over an orbital position in the GSO or any orbit. 134 Even if the Outer Space Treaty of 1967 prohibits countries from owning orbital slots in the GSO, the slots should still be allocated to countries that will use them, on a first-come, first-served basis. SBSP has so much potential to benefit all of [hu]mankind that if even a single country uses a GSO slot to gather power, the advantage of developing the technology of SBSP may outweigh the argument that all nations should have equal access to space.'3 5 Countries like Tonga that have no capability of sending satellites into orbit should not be able to claim GSO slots because this would prohibit developed countries from placing satellites into orbit that can benefit the whole world.136 The Outer Space Treaty of 1967 likely permits the allocation of GSO slots to individual countries on the condition that the slots are used for SBSP satellites that benefit all mankind. Countries with orbiting SBSP satellites could meet such conditional requirements in three ways. First, they could be required to provide power to less developed countries. Second, launching countries can help decrease global warming because SBSP satellites provide clean energy. Third, launching countries can lower the cost of solar power systems as they become cheaper and more affordable with time so that many less developed countries around the world will be able to access solar power from space. By satisfying any of these conditions, deployment of SBSP satellites would qualify under the treaty as "use of outer space ... carried out for the benefit and in the interests of all countries."'137 The universal benefits provided by SBSP satellites would therefore be consistent with the treaty's requirement that the use of outer space "shall be the province of all mankind." 138 Thus, while the Outer Space Treaty of 1967 may prohibit ownership of GSO slots, the temporary allocation of GSO slots for the use of SBSP satellites would be compatible with the goals of the treaty. ." As a result of the need to allow SBSP to have access to the GSO, there will need to be some sort of regulatory structure to GSO slot allocation. If a regulatory organization, such as the ITU, allows licensees to use a particular GSO position and microwave frequency, for a limited period of time, this would appear to satisfy the current international regime under the Outer Space Treaty of 1967. In order to comply with the treaty, countries would not have to surrender their slot or frequency, as they could simply allow other countries to lease the power satellites from them for a period of time. SBSP satellites in GSO would fall within the "province of mankind" requirement of the Outer Space Treaty of 1967 because SBSP can decrease global warming and help less developed countries by providing them with electricity in areas lacking infrastructure. Furthermore, SBSP satellites in GSO would satisfy the "peaceful purposes" requirement of the Outer Space Treaty of 1967 because the satellites are used for commercial power production and cannot be converted into weapons. 139

#### Lack of renewable energy causes a litany of impacts---food wars, fish wars, oxygen depletion, disease, and it’s a threat multiplier---tech is key to solve!

Wallace-Wells 17 – Deputy Editor NY Magazine, National Fellow New America [David, July 10, *New York Magazine*, “The Uninhabitable Earth, Annotated Edition”, <http://nymag.com/intelligencer/2017/07/climate-change-earth-too-hot-for-humans-annotated.html?gtm=bottom&gtm=top>, accessed 2/1/19]

We published “The Uninhabitable Earth” on Sunday night, and the response since has been extraordinary — both in volume (it is already the most-read article in New York Magazine’s history) and in kind. Within hours, the article spawned a fleet of commentary across newspapers, magazines, blogs, and Twitter, much of which came from climate scientists and the journalists who cover them. Some of this conversation has been about the factual basis for various claims that appear in the article. To address those questions, and to give all readers more context for how the article was reported and what further reading is available, we are publishing here a version of the article filled with research annotations. They include quotations from scientists I spoke with throughout the reporting process; citations to scientific papers, articles, and books I drew from; additional research provided by my colleague Julia Mead; and context surrounding some of the more contested claims. Since the article was published, we have made four corrections and adjustments, which are noted in the annotations (as well as at the end of the original version). They are all minor, and none affects the central project of the story: to apply the best science we have today to the median and high-end “business-as-usual” warming projections produced by the U.N.’s “gold standard” Intergovernmental Panel on Climate Change. But the debate this article has kicked up is less about specific facts than the article’s overarching conceit. Is it helpful, or journalistically ethical, to explore the worst-case scenarios of climate change, however unlikely they are? How much should a writer contextualize scary possibilities with information about how probable those outcomes are, however speculative those probabilities may be? What are the risks of terrifying or depressing readers so much they disengage from the issue, and what should a journalist make of those risks? I hope, in the annotations and commentary below, I have added some context. But I also believe very firmly in the set of propositions that animated the project from the start: that the public does not appreciate the scale of climate risk; that this is in part because we have not spent enough time contemplating the scarier half of the distribution curve of possibilities, especially its brutal long tail, or the risks beyond sea-level rise; that there is journalistic and public-interest value in spreading the news from the scientific community, no matter how unnerving it may be; and that, when it comes to the challenge of climate change, public complacency is a far, far bigger problem than widespread fatalism — that many, many more people are not scared enough than are already “too scared.” In fact, I don’t even understand what “too scared” would mean. The science says climate change threatens nearly every aspect of human life on this planet, and that inaction will hasten the problems. In that context, I don’t think it’s a slur to call an article, or its writer, alarmist. I’ll accept that characterization. We should be alarmed.

I. ‘Doomsday’

Peering beyond scientific reticence. It is, I promise, worse than you think. If your anxiety about global warming is dominated by fears of sea-level rise, you are barely scratching the surface of what terrors are possible, even within the lifetime of a teenager today. And yet the swelling seas — and the cities they will drown — have so dominated the picture of global warming, and so overwhelmed our capacity for climate panic, that they have occluded our perception of other threats, many much closer at hand. Rising oceans are bad, in fact very bad; but fleeing the coastline will not be enough. Indeed, absent a significant adjustment to how billions of humans conduct their lives, parts of the Earth will likely become close to uninhabitable, and other parts horrifically inhospitable, as soon as the end of this century. The most credible prediction of the effects of climate change comes from the U.N.’s Intergovernmental Panel on Climate Change, which issues regular reports synthesizing the latest science. The IPCC’s median business-as-usual projection for warming by 2100 is about four degrees, which would expose half the world’s population to unprecedented heat stress, according to Steven C. Sherwood and Matthew Huber’s landmark study on the subject. “I haven’t learned anything since publishing that paper,” Sherwood, a professor at UNSW Sydney, Kensington, told me. “It looks to me that at that those numbers — four to six degrees — you’d start to see the tropics evacuating, because people wouldn’t be able to live there. It might be less than four degrees. But around four degrees or five degrees, would be the point where people would be finding it unbearable.” It wouldn’t just be heat stress driving people away, he said. “A combination of heat stress and other things. I think you’d start to see crop failures, damage to the biosphere. Keep in mind, in the tropics, two or three degrees takes the environment outside the range of natural variability.” As Richard Alley of Pennsylvania State University told me, “under rapid emissions, by the end of the century, 40 percent of the ability of people to work outside would be lost.” How likely is this median, “business-as-usual” outcome? It’s difficult to say, unfortunately, given how many and how variable the inputs would be for any projections: emissions rates, the pace of technological change, cultural changes, and public policy, all on top of what is already a quite complicated (and not entirely understood) natural system that delivers both amplifying and moderating feedbacks to human-produced greenhouse-gas effects. In some ways, it is easiest to talk about that business-as-usual model, because it holds so many of those variables constant. But, since a number of readers have wondered about those probabilities, I’ll mention a couple of estimates that seemed helpful, to me, in establishing the general lay of the land. In my interview with Michael Oppenheimer, of Princeton, he told me that he’d estimate our chances of staying below the Paris accord’s goal of two-degrees warming at 10 percent. In my interview with Wallace Smith Broecker, of Columbia, he mentioned some research he’d followed whereby researchers ran a single model many, many times to generate a range of probabilities; “The mean was about 3.5 degrees Celsius of warming,” he told me. “But it showed there was something like 15 percent probability that it’d be more than four degrees, just on these model runs.” And in their book Climate Shock: The Economic Consequences of a Hotter Planet, Gernot Wagner and Martin Weitzman estimate a 15 percent chance that we overshoot six degrees. These models make a variety of assumptions, both about natural systems and manmade response, but collectively they do suggest, to me at least, that we have been far too focused on the optimistic possibilities (which bring us to 2100 at or under two degrees warming) and not nearly focused enough on the more dire ones. As Joseph Romm wrote in Climate Change: What Everyone Needs to Know, “Any time this book or any news report cites an IPCC projection of future warming or future climate impacts, it is almost certain that projection represents an underestimate of what is to come.” Even when we train our eyes on climate change, we are unable to comprehend its scope. This past winter, a string of days 60 and 70 degrees warmer than normal baked the North Pole,“This is a little bit shocking,” Ketil Isaksen of the Norwegian Meteorological Institute said of the temperatures. melting the permafrost “When we built the seed vault, there was not even discussion of the permafrost,” Hege Njaa Aschim, the press representative of the organization that oversees the project, told me. But the weather last winter, she said, was “like a Norwegian summer.” “We didn’t come up with the term doomsday vault,” Cary Fowler, the mastermind of the seed vault, told me. “The idea there was to provide an insurance policy, so if anything were to happen to those other facilities, it wouldn’t be an extinction event.” that encased Norway’s Svalbard seed vault — a global food bank nicknamed “Doomsday,” designed to ensure that our agriculture survives any catastrophe, and which appeared to have been flooded by climate change less than ten years after being built. The Doomsday vault is fine, for now: The structure has been secured and the seeds are safe.Fowler was emphatic on this point to me — there had been a wave of press coverage that presented the flooding as something catastrophic, rather than a breach that let meltwater in just 15 or 20 meters down a much-longer tunnel that leads from the exterior of the mountain into the seed vault’s “cathedral” room, from which the storage facilities fan. But treating the episode as a parable of impending flooding missed the more important news. Until recently, permafrost was not a major concern of climate scientists, because, as the name suggests, it was soil that stayed permanently frozen. But Arctic permafrost contains 1.8 trillion tons of carbon,In this paper, it’s calculated by petagrams; 1,672 petagrams is about 1.8 trillion tons. more than twice as muchThis is from Joseph Romm’s Climate Change, page 81 (in the paperback edition). The book was an invaluable resource in researching this article, and I highly recommend it to anyone interested in picking up where this piece leaves off. as is currently suspended in the Earth’s atmosphere. When it thaws and is released, that carbon may evaporate as methane, which is 34 times as powerful a greenhouse-gas warming blanket as carbon dioxide when judged on the timescale of a century; when judged on the timescale of two decades, it is 86 times as powerful.This is also from Romm, also page 81. You can read more about methane’s greenhouse effects here. In other words, we have, trapped in Arctic permafrost, twice as much carbon as is currently wrecking the atmosphere of the planet, all of it scheduled to be released at a date that keeps getting moved up, partially in the form of a gas that multiplies its warming power 86 times over.There has been a fair amount of criticism of my use of this material. Michael Mann in particular has faulted me for it; in his initial Facebook post about the story, he wrote that “the science doesn’t support the notion of a game-changing, planet-melting methane bomb.” At Climate Feedback, several other scientists took issue with various aspects of my characterization as well. ¶ There is little doubt that this permafrost is melting quickly. According to the IPCC’s Fifth Assessment, by 2100, “it is virtually certain that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average.” But there is some important context I did not include here: Few scientists believe there is a substantial risk of methane release from permafrost happening suddenly, or all at once. Also, most of the carbon will likely escape as C02, not methane. In retrospect, I sympathize with those who find misleading the phrase “all of it scheduled to be released at a date that keeps getting moved up.” The schedule I was referring to was the melting, which will take decades; the thawing is a process, not an event. ¶ I believe that my original description of the possibility of the methane release lacked some relevant (reassuring) context. But I do not believe the science was fundamentally misrepresented here: There is that much carbon in the permafrost; the permafrost is melting at accelerating rates; some of the carbon will be released as methane; and methane is a stronger greenhouse gas than carbon dioxide. ¶ My intention in referencing the permafrost was to illustrate, for readers unfamiliar with the particulars of projection models, how many uncertain factors were at play — how many forces we don’t understand, and how possibly significant those forces could be in the warming of the planet. As Joseph Romm writes, “The thawing tundra or permafrost may well be the single most important amplifying carbon-cycle feedback. Yet, none of the Intergovernmental Panel on Climate Change’s climate models include carbon dioxide or methane emissions from warming tundra as a feedback.” He also writes, “A 2011 study by the U.S. National Oceanic and Atmospheric Administration and the National Snow and Ice Data Center found that thawing permafrost will turn the Arctic from a place that stores carbon (a sink) to a place that generates carbon (a source) in the 2020s—and release a hundred billion tons of carbon by 2100.” That study, he says, assumes none of the carbon will be released as methane, and yet still predicts a release “equivalent to half the amount of carbon that has been released into the atmosphere since the dawn of the industrial age.” ¶ To be additionally clear, none of the warming scenarios described in the remainder of this article are built on the premise of a methane release from permafrost. They all extrapolate from the median and high-end IPCC projections for business-as-usual warming. Even if you take issue with my characterization of the threat from permafrost melt, it does not affect my discussion of any of the risks that follow. The permafrost melt is a wild card which could add to those IPCC projections. (Romm calculates it could add a degree of warming by 2100 all on its own.) ¶ For those who are really interested in reading about methane, there are also the clathrates to consider — bubbles of methane at the bottom of the ocean, which many energy companies are now hoping to mine. Speaking about those with me, Lee Kump, a Penn State geoscientist, had this to say: “We haven’t really anticipated these positive feedbacks — for instance, these pockets of methane. That methane starts bubbling out, that’s a potent greenhouse gas. As that spreads throughout the globe, there’s a tremendous potential there for methane hydrates release.” He went on: “As you move towards the poles, we’re already seeing the consequences of warming there in terms of methane release.” Maybe you know that already — there are alarming stories in the news every day, like those, last month, that seemed to suggest satellite data showed the globe warming since 1998 more than twice as fast as scientists had thought (in fact, the underlying story was considerably less alarming than the headlines).This reference to recent, alarming news generated a fair amount of pushback among scientists. We’ve adjusted the text to make clear that, while many outlets did describe the study in these terms — in the Washington Post, for instance: “Satellite temperature data, leaned on sharply by climate change doubters, revised sharply upward”) — the actual news was much less dramatic. There was satellite data that was revised upward, but it was data that had been previously interpreted to be below estimates and adjacent data sets, and was revised to bring it more or less into line with those estimates and data sets (that is, it did not change the big-picture assessment of how fast the planet was warming). In general, I agree with this characterization, by Carl Mears, who wrote the study: “This sentence is true for RSS data,” he told Climate Feedback. “But it’s somewhat misleading due to lack of context.” The paper on which the news was based can be found here. Or the news from Antarctica this past May, when a crack in an ice shelf grew 11 miles in six days, then kept going; the break now has just three miles to go — by the time you read this, it may already have met the open water, where it will drop into the sea one of the biggest icebergs ever, a process known poetically as “calving.”As readers have pointed out, there is a debate within the scientific community about whether this calving is a natural process or the result of climate change. In either case, it is alarming news, given that the ice now loosed into the ocean will melt faster. And, of course, the calving has since occurred. But no matter how well-informed you are, you are surely not alarmed enough. Over the past decades, our culture has gone apocalyptic with zombie movies and Mad Max dystopias, perhaps the collective result of displaced climate anxiety, and yet when it comes to contemplating real-world warming dangers, we suffer from an incredible failure of imagination. The reasons for that are many: the timid language of scientific probabilities, which the climatologist James Hansen once called “scientific reticence”. That paper can be found here. Hansen spoke about this with me: “You’re rewarded in science for not stepping out too rapidly,” he said. in a paper chastising scientists for editing their own observations so conscientiously that they failed to communicate how dire the threat really was; the fact that the country is dominated by a group of technocrats who believe any problem can be solved and an opposing culture that doesn’t even see warming as a problem worth addressing; the way that climate denialism has made scientists even more cautious in offering speculative warnings; the simple speed of change and, also, its slowness, such that we are only seeing effects now of warming from decades pastHansen also spoke about this with me: “The fundamental difficulty is the delayed response — the inertia of the climate system. The ocean is deep and the ice sheets are three kilometers thick, and they don’t respond quickly to what is really a weak forcing. And so the system has only partially responded to the forcing we’ve put up already. There’s more in the pipeline. You’re talking about a system that responds on the timescale of decades to centuries — that’s a different time constant than the political constant.” ; our uncertainty about uncertainty, which the climate writer Naomi Oreskes in particular has suggested stops us from preparing as though anything worse than a median outcome were even possibleOne especially good paper by Oreskes can be found here. ; the way we assume climate change will hit hardest elsewhere, not everywhere; the smallness (two degreesThis is the warming target, in Celsius, of the Paris climate accord agreement. ) and largeness (1.8 trillion tonsThis is the amount of carbon in the permafrost (see note No. 8). ) and abstractness (400 parts per millionThis is the current concentration of CO2 in the atmosphere. ) of the numbers; the discomfort of considering a problem that is very difficult, if not impossible, to solve; the altogether incomprehensible scale of that problem, which amounts to the prospect of our own annihilation; simple fear. But aversion arising from fear is a form of denial, too. In between scientific reticence and science fiction is science itself. This article is the result of dozens of interviews and exchanges with climatologists and researchers in related fields and reflects hundreds of scientific papers on the subject of climate change. What follows is not a series of predictions of what will happen — that will be determined in large part by the much-less-certain science of human response. Instead, it is a portrait of our best understanding of where the planet is heading absent aggressive action. It is unlikely that all of these warming scenarios will be fully realized, largely because the devastation along the way will shake our complacency. But those scenarios, and not the present climate, are the baseline. In fact, they are our schedule.These five sentences were the focal point of much of the debate among scientists surrounding this piece: Were they explicit enough to explain to readers that this article would be a tour of worst-case scenarios, and was not intended to be read as a prediction of likely outcomes? And furthermore, was such a worst-case-scenario tour irresponsible, given that they are not the most likely scenarios? For some of the most thoughtful commentary on all sides of the debate, I recommend reading the essays by Susan Matthews, David Roberts, and Robinson Meyer. The present tense of climate change — the destruction we’ve already baked into our future — is horrifying enough.Joseph Romm, in Climate Change: “Many cornerstone elements of our climate began changing far faster than most scientists had projected. The Arctic began losing sea ice several decades ahead of every single climate model used by the IPCC, which in turn means the Arctic region warmed up even faster than scientists expected. At the same time, the great ice sheets of Greenland and Antarctica, which contain enough water to raise sea levels ultimately 25–80 meters (80–260 feet), have begun disintegrating ‘a century ahead of schedule,’ as Richard Alley, a leading climatologist put it in 2005. In 2014 and 2015, we learned that both ice sheets are far less stable than we realized, and they are dangerously close to tipping points that would lead to irreversible collapse and dramatic rates of sea level rise.” Most people talk as if Miami and Bangladesh still have a chance of surviving; most of the scientists I spoke with assume we’ll lose them within the century, even if we stop burning fossil fuel in the next decade.Peter Ward told me Bangladesh is “doomed”: “The worst place on earth has to be Bangladesh, because it’s not just the covering, it’s the sideways salt problem that will doom them.The scary thing is that, the direct cover is what people cite, but they ignore, to date, the sideways infiltration of salt. And this, again, just a slight rise in sea level causes a huge problem. And, as you know, as the sea level rises, it’s like a diving board for storm surge. You’re causing storm surge to jump ever further inland, and that in itself means huge inundation — it doesn’t have to be the rise to destroy the crops. It’s just a bad, bad situation. Bangladesh — you cover it up, where are those people going to go?” ¶ In Bangladesh, 40 percent of land is projected to be lost with just 65 centimeters (just over two feet) sea-level rise. Could some of this flooding be avoided if the world zeroed out emissions immediately and entirely (if the Paris accords legislated 100 percent carbon-neutral energy and industry and land use)? Some, possibly. But one 2012 study by Climate Analytics suggested that even if the planet eliminated emissions entirely by 2016 a best-possible-case outcome would be sea-level rise of 59 centimeters by 2100 — just about exactly that two feet of rise that would cover 40 percent of the country. ¶ A few of the other scientists I spoke with weren’t quite as definitive as Ward, but in general agreed that no plausible emissions-reduction regime could stop the planet from reaching about 1.5 degrees warming by the end of the century, which will produce some quite problematic sea-level effect. “Forty or 50 years from now we’ll be at doubled carbon dioxide,” Wallace Smith Broecker told me. “And that will be away above — we may not be above two degrees at that point, because the ocean is sucking up a lot of heat, and we have to heat up the ocean. And that’s one thing — the melting of the ice. Of course that involves almost all the major cities in the world, which are on the ocean. Bangladesh and Florida and so forth.” That same two-foot sea-level rise would increase flooding in Miami Beach and other Miami barrier islands about a hundredfold, according to Doug Marcy of the NOAA, working from data centered on nearby Virginia Key. Here is one good report on the threat to Miami and South Florida generally. Two degrees of warming used to be considered the threshold of catastrophe: tens of millions of climate refugees unleashed upon an unprepared world.James Hansen has been especially vocal about the risks of a two-degrees-warmer world. Now two degrees is our goal, per the Paris climate accords, and experts give us only slim odds of hitting it.For instance, this expert. The U.N. Intergovernmental Panel on Climate Change issues serial reports, often called the “gold standard” of climate research; the most recent one projects us to hit four degrees of warming by the beginning of the next century, should we stay the present course. But that’s just a median projection. The upper end of the probability curve runs as high as eight degreesSee the U.N,’s Summary for Policymakers. — and the authors still haven’t figured out how to deal with that permafrost melt. The IPCC reports also don’t fully account for the albedo effect (less ice means less reflected and more absorbed sunlight, hence more warming); more cloud cover (which traps heat)At Climate Feedback, Ted Letcher calls this a “gross oversimplification.” However, he goes on to say that, “The IPCC report does generally show a net positive cloud feedback, indicating global cloud feedbacks will lead to additional warming.” ; or the dieback of forests and other flora (which extract carbon from the atmosphere).Some of these effects are included in the IPCC reports, but this assessment of how fully they’ve been incorporated comes from a fact-checking conversation with Michael Oppenheimer (separate from the original reporting interview). Oppenheimer is not only one of the world’s leading authorities on climate change, he has also been closely involved through the years with the IPCC project. Some scientists have argued that the IPCC has modeled some of these effects, and they are correct in the sense that the reports include many, many divergent models, emphasized to different degrees and given different amounts of prominence in their reports. But on the question of just how fully those reports account for these effects, I’m with Oppenheimer. Each of these promises to accelerate warming,As some scientists have pointed out, there are also feedback loops that work in the opposite direction, though they are generally considered to be less powerful, so that the net effect remains “positive” (that is, amplifying warming). As Joseph Romm points out, “In 2011, Science published a major review, ‘Lessons from Earth’s Past,’ which suggested that carbon dioxide ‘may have at least twice the effect on global temperatures than currently projected by computer models.’” and the history of the planet shows that temperature can shift as much as five degrees Celsius within thirteen years.This phrase has been updated to more accurately reflect the rate of warming during the Paleocene–Eocene Thermal Maximum. The last time the planet was even four degrees warmer, Peter Brannen points out in The Ends of the World, his new history of the planet’s major extinction events,Brannen’s book is a very engaging way into the history of mass extinctions (and he was a very helpful interview, too). This sentence was updated to correct a reference to Brannen’s book. the oceans were hundreds of feet higher.\* The Earth has experienced five mass extinctionsHere is an even shorter way into the history. before the one we are living through now,In their book Dire Predictions, Michael Mann and Lee Kump estimate that four degrees of warming would eliminate between 40 and 70 percent of the world’s species. At 2.2 degrees, we’d lose between 15 and 37 percent. each so complete a slate-wiping of the evolutionary record it functioned as a resetting of the planetary clock,“To me, the mass extinctions were really interesting in terms of what happens after them — we have this dead period, and the recovery fauna is totally different,” Peter Ward told me. “And that leads to the idea of, Gee, how much longer will the recovery be if we have an extinction now?” and many climate scientists will tell you they are the best analog for the ecological future we are diving headlong into.“To find analogue worlds for the future, we have to go way back in Earth’s history,” Lee Kump told me. “Each of these events, including the modern situation, starts with a trigger. In the past it’s been a volcanic eruption, now it’s fossil-fuel burning, but it’s a very analogous perturbation to the system. But then it’s amplified by hidden feedbacks that get activated from the initial warming, and bring that warming even further.” Unless you are a teenager, you probably read in your high-school textbooks that these extinctions were the result of asteroids. In fact, all but the one that killed the dinosaurs were caused by climate change produced by greenhouse gas.“Impact was key, and king, for the 1980s and 1990s — every one of the big extinctions was attributed to impact,” Peter Ward told me. “But it became clear that, in fact, no, these were not impact extinctions. We had to invent a new term. I don’t know who came up with it first, but I was in there pretty early calling them greenhouse extinctions. And this new paradigm started coming into play. We’re even starting to see that K–T [the extinction that killed off the dinosaurs] also has a greenhouse component — because there was warming right at the impact.” The most notorious was 252 million years ago; it began when carbon warmed the planet by five degrees, accelerated when that warming triggered the release of methane in the Arctic, and ended with 97 percent of all life on Earth dead.For more about the end-Permian mass extinction, see this National Geographic article, this article from Phys.org, and my interview with Peter Ward. In Climate Feedback’s scientist survey, Lee Kump took issue with my description of the role of methane in the end-Permian extinction: “Whether methane was released remains speculative, although not unlikely.” Speaking about the same extinction event to me, he was much less equivocal: “That was triggered by volcanic eruption — in this case in Siberia, one of the biggest volcanic events of all time. And that had the predictable effects — release of CO2, methane, and ultimately mass extinctions.” We are currently adding carbon to the atmosphere at a considerably faster rate; by most estimates, at least ten times faster.“Maximum rates of carbon emissions for both the PETM and the end-Permian is about 1 billion tons of carbon, and right now we’re at 10 billion tons of carbon,” Lee Kump told me. “The duration of both of those events was much longer than fossil-fuel burning will go on, and so the total amount is lower — but not by a factor of ten. By a factor of two or three.” According to the World Bank, “The present CO2 concentration is higher than paleoclimatic and geologic evidence indicates has occurred at any time in the last 15 million years.” The rate is accelerating.“It’s going completely in the wrong direction, with no sign that the planet as a whole has the problem under control,” Kevin Trenberth, a senior scientist at the National Center for Atmospheric Research, told Inside Climate News. As Joseph Romm puts it, “The current rate of increase in global warming is roughly the same as detonating 400,000 Hiroshima bombs per day, 365 days per year.” This is what Stephen Hawking had in mind when he said, this spring, that the species needs to colonize other planets in the next century to survive, and what drove Elon Musk, last month, to unveil his plans to build a Mars habitat in 40 to 100 years. These are nonspecialists, of course, and probably as inclined to irrational panic as you or I. But the many sober-minded scientists I interviewed over the past several months — the most credentialed and tenured in the field, few of them inclined to alarmism and many advisers to the IPCC who nevertheless criticize its conservatism — have quietly reached an apocalyptic conclusion, too: No plausible program of emissions reductions alone can prevent climate disaster.See, for instance, my interviews with James Hansen and Wallace Smith Broecker. Over the past few decades, the term “Anthropocene” has climbed out of academic discourse and into the popular imagination — a name given to the geologic era we live in now, and a way to signal that it is a new era, defined on the wall chart of deep history by human intervention. One problem with the term is that it implies a conquest of nature (and even echoes the biblical “dominion”). And however sanguine you might be about the proposition that we have already ravaged the natural world, which we surely have, it is another thing entirely to consider the possibility that we have only provoked it, engineering first in ignorance and then in denial a climate system that will now go to war with us for many centuries, perhaps until it destroys us. That is what Wallace Smith Broecker, the avuncular oceanographer who coined the term “global warming,” means when he calls the planet an “angry beast.”“The climate system is an angry beast and we are poking it with sticks.” You could also go with “war machine.” Each day we arm it more.

II. Heat Death

The bahraining of New York. In the sugar­cane region of El Salvador, as much as one-fifth of the population has chronic kidney disease, the presumed result of dehydration from working the fields they were able to comfortably harvest as recently as two decades ago. Photo: Heartless Machine Humans, like all mammals, are heat engines; surviving means having to continually cool off, like panting dogs. For that, the temperature needs to be low enough for the air to act as a kind of refrigerant, drawing heat off the skin so the engine can keep pumping. At seven degrees of warming, that would become impossible for large portions of the planet’s equatorial band, and especially the tropics, where humidity adds to the problemThis is from the landmark paper on the subject, by Steven C. Sherwood and Matthew Huber. ; in the jungles of Costa Rica, for instance, where humidity routinely tops 90 percent, simply moving around outside when it’s over 105 degrees Fahrenheit would be lethal. You can use this rough wet-bulb-temperature calculator to explore other circumstances. And the effect would be fast: Within a few hours, a human body would be cooked to death from both inside and out. This is based on research by Sherwood, which can be found here. Climate-change skeptics point out that the planet has warmed and cooled many times before, but the climate window that has allowed for human life is very narrow, even by the standards of planetary history. At 11 or 12 degrees of warming, more than half the world’s population, as distributed today, would die of direct heat.Sherwood and Huber again. Things almost certainly won’t get that hot this century, though models of unabated emissions do bring us that far eventually.“One of the problems in the IPCC is that they only want to focus on what happens in the year 2100. If you go out to 2300, it’s not hard to get past six degrees — half the models do that,” Sherwood told me by phone. Later, by email, he added: “Several of the models run for the last IPCC report eventually reach more than 10C of warming under a no-mitigation scenario (though not until the next century or the one after). You could say it is unlikely. Most models eventually exceed 6C though, so this is actually unlikely \*not\* to happen without mitigation!” This century, and especially in the tropics, the pain points will pinch much more quickly even than an increase of seven degrees. The key factor is something called wet-bulb temperature, which is a term of measurement as home-laboratory-kit as it sounds: the heat registered on a thermometer wrapped in a damp sock as it’s swung around in the air (since the moisture evaporates from a sock more quickly in dry air, this single number reflects both heat and humidity). At present, most regions reach a wet-bulb maximum of 26 or 27 degrees Celsius; the true red line for habitability is 35 degrees. What is called heat stress comes much sooner.Sherwood and Huber again. Actually, we’re about there already. Since 1980, the planet has experienced a 50-fold increase in the number of places experiencing dangerous or extreme heatThe original paper is by James Hansen, though for this and much of my account of extreme heat events I relied on Joseph Romm’s Climate Change. ; a bigger increase is to come. The five warmest summers in Europe since 1500 have all occurred since 2002,This is from the World Bank’s very helpful 2012 report Turn Down the Heat, on life in a world four degrees warmer. and soon, the IPCC warns, simply being outdoors that time of year will be unhealthy for much of the globe.The warning appears on page 15 of the Fifth Assessment’s Synthesis Report. As some readers have pointed out, these effects will come about gradually, beginning with the rare unusually hot day; those unusually hot days will gradually become more frequent in number. As with all of the climate effects in this article, it’s important to remember that heat stress is not a binary matter: It’s not that there are two options, lethal heat waves and normal, comfortable temperatures, but that global warming will gradually bring about more and more heat stress. The same is true, of course, for effects on agriculture, economics, conflict, and other areas. As Richard Alley told me, “We’ve warmed the world one degree. The general impression is that each degree is more costly, more damaging, than the previous one. The first degree — most estimates are that the first degree was almost free. But we can see a dotted line into Syria. The second degree will cost more than the first degree. You might say it costs the square of the warming.” Even if we meet the Paris goals of two degrees warming, cities like Karachi and Kolkata will become close to uninhabitable, annually encountering deadly heat waves like those that crippled them in 2015.“Even if such aspirations are realized, large increases in the frequency of deadly heat should be expected, with more than 350 million more megacity inhabitants afflicted by midcentury,” this paper warns. At four degrees, the deadly European heat wave of 2003, which killed as many as 2,000 people a day, will be a normal summer. Also from Turn Down the Heat. At six, according to an assessment focused only on effects within the U.S. from the National Oceanic and Atmospheric Administration, summer labor of any kind would become impossible in the lower Mississippi Valley, and everybody in the country east of the Rockies would be under more heat stress than anyone, anywhere, in the world today.The report can be found here. As Joseph Romm has put it in his authoritative primer Climate Change: What Everyone Needs to Know, heat stress in New York City would exceed that of present-day Bahrain, one of the planet’s hottest spots, and the temperature in Bahrain “would induce hyperthermia in even sleeping humans.”This is from page 138, though it refers to the same NOAA study mentioned above. The high-end IPCC estimate, remember, is two degrees warmer still. By the end of the century, the World Bank has estimated, the coolest months in tropical South America, Africa, and the Pacific are likely to be warmer than the warmest months at the end of the 20th century.See Turn Down the Heat. Air-conditioning can help but will ultimately only add to the carbon problem; plus, the climate-controlled malls of the Arab emirates aside, it is not remotely plausible to wholesale air-condition all the hottest parts of the world, many of them also the poorest.The air-conditioning/carbon trade-off is especially acute in developing countries. And indeed, the crisis will be most dramatic across the Middle East and Persian Gulf, where in 2015 the heat index registered temperatures as high as 163 degrees Fahrenheit.This was in Iran. As soon as several decades from now, the hajj will become physically impossible for the 2 million Muslims who make the pilgrimage each year.This study, by Jeremy S. Pal and Elfatih A. B. Eltahir, was also written about in the New York Times. It is not just the hajj, and it is not just Mecca; heat is already killing us. In the sugarcane region of El Salvador, as much as one-fifth of the population has chronic kidney disease, including over a quarter of the men, the presumed result of dehydration from working the fields they were able to comfortably harvest as recently as two decades ago.A good account of this phenomenon appeared in Australia’s The Age (flagged for me by Steven Sherwood). With dialysis, which is expensive, those with kidney failure can expect to live five years; without it, life expectancy is in the weeks.“Average life expectancy on dialysis is 5–10 years,” the National Kidney Foundation estimates. Of course, heat stress promises to pummel us in places other than our kidneys, too. As I type that sentence, in the California desert in mid-June, it is 121 degrees outside my door.This was in Palm Springs. It is not a record high.But close.

III. The End of Food

Praying for cornfields in the tundra. Climates differ and plants vary, but the basic rule for staple cereal crops grown at optimal temperature is that for every degree of warming, yields decline by 10 percent.The major paper on this subject is by David S. Battisti and Rosamond L. Naylor. Some estimates run as high as 15 or even 17 percent.“Under optimal conditions — these are controlled plots, where they have irrigation and pesticides — you get this kind of typical, between 10 percent and 17 percent decline for every degree Celsius of increase,” David Battisti told me. “But people will say, ‘What about the carbon fertilization?’” That has been thought to aid plant growth, a kind of airborne fertilizer. “Everything I’ve seen about CO2 fertilization — none of it is helpful for grains. It might be helpful for biomass, but it’s not helpful for grains. And so, yeah, if you want to eat the leaves of the wheat plant, it might be okay. But if you want to eat the wheat, it’s not necessarily good.” Which means that if the planet is five degrees warmer at the end of the century, we may have as many as 50 percent more people to feed and 50 percent less grain to give them.In my interview with Battisti, I suggested this arithmetic: four or five degrees warming means 50 or 60 percent drop in yields, for a population that will be 50 to 75 percent higher. “That’s right, that’s right,” he said. “Yup, yup. And there are some things you could do. You could have some of these countries develop and not turn to a meat diet, which would help a little bit. Obviously, when people get wealthier their diet shifts more to a meat diet, which means you need grain to feed cows and pigs and chickens. And every country — even India is shifting to be more meat consumption per person, though it’s a small shift because of religious reasons, but every other country lies on the same curve. As the income goes up, the consumption of meat goes up. Which means the demand for grains will go through the roof.” And proteins are worse: It takes 16 calories of grain to produce just a single calorie of hamburger meat,Battisti: “There are these seed-conversion rates that range from a factor of— very low is three, three kilograms of protein that you feed a fish for one kilogram you get out of it. For beef, it’s ten. And, you end up with massive amounts of grain to feed pigs and chickens.” butchered from a cow that spent its life polluting the climate with methane farts.Cows both burp and fart methane, although the burps are actually worse; National Geographic recently wrote that cow burps are responsible for 26 percent of U.S. methane release. Pollyannaish plant physiologists will point out that the cereal-crop math applies only to those regions already at peak growing temperature, and they are right — theoretically, a warmer climate will make it easier to grow corn in Greenland. But as the pathbreaking work by Rosamond Naylor and David Battisti has shown, the tropics are already too hot to efficiently grow grain, and those places where grain is produced today are already at optimal growing temperature — which means even a small warming will push them down the slope of declining productivity.“If you’re beyond the optimal temperature, as in the tropics, as you increase temperature, yields decline,” Battisti said. “In the mid-latitudes, people haven’t worried so much, because we live near the optimal temperature for growing grains. But the thing is, there’s a lot of natural variability in growing-season temperature in the mid-latitudes, compared to the tropics. Tropics are steady. So you have this same wobbling around of temperatures, but I’ve warmed enough so I’m now on the downside of that optimal slope, than it means you’re wobbling all over the slope, anything from perfectly warm conditions, like we have today, to way too warm, as we have today in the tropics. So the volatility in the yield will go through the roof. And our calculations show that. By 2050, under a typical middle-of-the-road emissions scenario, you’re looking at a doubling of the volatility for grains in the mid-latitudes. In places like China, the U.S., Europe, Ukraine — the breadbasket countries of the world — the volatility from year to year just from natural climate variability at a higher temperature is going to much higher. The impact on the crops is going to be greater and greater.” And you can’t easily move croplands north a few hundred miles, because yields in places like remote Canada and Russia are limited by the quality of soil there; it takes many centuries for the planet to produce optimally fertile dirt.“Pretty much all the arable land worth farming is already being farmed, so I’m not sure you can say where to go,” Battisti told me. So warming couldn’t help production at higher latitudes? I asked. “No, no. You’d really have no change in higher latitudes, simply because it takes a long time for soil to be prepared to grow grain. A lot of places, you go north in Canada, you run out of soil. You run out of conditions to grow. Part of it is climate, and part of it is grow quality. There was a pretty big piece of ice up there not so long ago, and there’s not enough topsoil to grow grains.” According to the U.N.’s Food and Agriculture Organization, it takes about 1,000 years for three centimeters of topsoil to form. Drought might be an even bigger problem than heat, with some of the world’s most arable land turning quickly to desert.“As much as one third of the Earth’s currently habited and arable land faces a near permanent drying this century,” Joseph Romm writes in Climate Change. Precipitation is notoriously hard to model, yet predictions for later this century are basically unanimous: unprecedented droughts nearly everywhere food is today produced.Peter Brannen, in Ends of the World: “By the year 2050, according to a 2014 MIT study, there will also be 5 billion people living in water-stressed areas.” By 2080, without dramatic reductions in emissions, southern Europe will be in permanent extreme drought, much worse than the American dust bowl ever was.See “Global warming and 21st century drying,” a 2014 study led by Benjamin I. Cook. The same will be true in Iraq and Syria and much of the rest of the Middle East; some of the most densely populated parts of Australia, Africa, and South America; and the breadbasket regions of China.This is from Romm, page 99. None of these places, which today supply much of the world’s food, will be reliable sources of any. As for the original dust bowl: The droughts in the American plains and Southwest would not just be worse than in the 1930s, a 2015 NASA study predicted, but worse than any droughts in a thousand years — and that includes those that struck between 1100 and 1300, which “dried up all the rivers East of the Sierra Nevada mountains” and may have been responsible for the death of the Anasazi civilization.The quote is Romm, working off this study, summarized here. Remember, we do not live in a world without hunger as it is. Far from it: Most estimates put the number of undernourished at 800 million globally.Technically, the World Hunger Organization puts the number at 795 million. In case you haven’t heard, this spring has already brought an unprecedented quadruple famine to Africa and the Middle East; the U.N. has warned that separate starvation events in Somalia, South Sudan, Nigeria, and Yemen could kill 20 million this year alone.Read about it from the U.N. here.

IV. Climate Plagues

What happens when the bubonic ice melts? Rock, in the right spot, is a record of planetary history, eras as long as millions of years flattened by the forces of geological time into strata with amplitudes of just inches, or just an inch, or even less. Ice works that way, too, as a climate ledger, but it is also frozen history, some of which can be reanimated when unfrozen. There are now, trapped in Arctic ice, diseases that have not circulated in the air for millions of years — in some cases, since before humans were around to encounter them.The BBC recently covered this well. Which means our immune systems would have no idea how to fight back when those prehistoric plagues emerge from the ice. The Arctic also stores terrifying bugs from more recent times. In Alaska, already, researchers have discovered remnants of the 1918 flu They actually extracted it from the cadaver of a frozen woman. that infected as many as 500 million and killed as many as 100 million — about 5 percent of the world’s population and almost six times as many as had died in the world war for which the pandemic served as a kind of gruesome capstone. As the BBC reported in May, scientists suspect smallpox and the bubonic plague are trapped in Siberian ice, too — an abridged history of devastating human sickness, left out like egg salad in the Arctic sun. Experts caution that many of these organisms won’t actually survive the thaw and point to the fastidious lab conditions under which they have already reanimated several of them — the 32,000-year-old “extremophile” bacteria revived in 2005,This one came immediately back to life. an 8 million-year-old bug brought back to life in 2007,This one grew very slowly when revived. the 3.5 million–year–old one a Russian scientist self-injected just out of curiosity“Just to see what would happen,” as Vice wrote in their profile of the scientist. Watch him on YouTube, here. — to suggest that those are necessary conditions for the return of such ancient plagues.Jean-Michel Claverie and colleagues, for instance, have published on this debate. But already last year, a boy was killed and 20 others infected by anthrax released when retreating permafrost exposed the frozen carcass of a reindeer killed by the bacteria at least 75 years earlier; 2,000 present-day reindeer were infected, too, carrying and spreading the disease beyond the tundra.The Guardian had a good news story about this episode; anthrax had not previously been seen in the region since 1941. What concerns epidemiologists more than ancient diseases are existing scourges relocated, rewired, or even re-evolved by warming. The first effect is geographical. Before the early-modern period, when adventuring sailboats accelerated the mixing of peoples and their bugs, human provinciality was a guard against pandemic. Today, even with globalization and the enormous intermingling of human populations, our ecosystems are mostly stable, and this functions as another limit, but global warming will scramble those ecosystems and help disease trespass those limits as surely as Cortés did. You don’t worry much about dengue or malaria if you are living in Maine or France. But as the tropics creep northward and mosquitoes migrate with them, you will. You didn’t much worry about Zika a couple of years ago, either. As it happens, Zika may also be a good model of the second worrying effect — disease mutation. One reason you hadn’t heard about Zika until recently is that it had been trapped in Uganda; another is that it did not, until recently, appear to cause birth defects. Scientists still don’t entirely understand what happened, or what they missed.One of the major problems here is that scientists lack much data about how Zika has affected humans in the past. For some hypotheses about this mystery, see this reporting by Time. But there are things we do know for sure about how climate affects some diseases: Malaria, for instance, thrives in hotter regions not just because the mosquitoes that carry it do, too, but because for every degree increase in temperature, the parasite reproduces ten times faster.The effect varies based on latitude, humidity, and other factors, but this research is a good place to start reading. Which is one reason that the World Bank estimates that by 2050, 5.2 billion people will be reckoning with it.“The total population at risk in 2050 is projected to be about 5.2 billion if only climate impacts are considered,” the World Bank says in Turn Down the Heat. To be clear, “reckoning” does not mean that 5.2 billion people will be infected with malaria, but that that many people will live in conditions where they could potentially be infected.

V. Unbreathable Air

A rolling death smog that suffocates millions. Our lungs need oxygen, but that is only a fraction of what we breathe. The fraction of carbon dioxide is growing: It just crossed 400 parts per million, and high-end estimates extrapolating from current trends suggest it will hit 1,000 ppm by 2100. At that concentration, compared to the air we breathe now, human cognitive ability declines by 21 percent. The science on this subject is young, but here are two studies. There is also a good summary of the research and its limitations in Joseph Romm’s Climate Change, pages 112–118. Other stuff in the hotter air is even scarier, with small increases in pollution capable of shortening life spans by ten years.“An increase in pollution particles in the air of 10 micrograms per cubic meter cuts victims’ life expectancy by 9-11 years,” one recent study showed. The warmer the planet gets, the more ozone forms, and by mid-century, Americans will likely suffer a 70 percent increase in unhealthy ozone smog, the National Center for Atmospheric Research has projected.That study is from 2014, and can be found here. By 2090, as many as 2 billion people globally will be breathing air above the WHO “safe” levelFrom Joseph Romm, summarizing a report from the U.K.’s Met Office Hadley Centre. ; one paper last month showed that, among other effects, a pregnant mother’s exposure to ozone raises the child’s risk of autism (as much as tenfold, combined with other environmental factors).This study was published only last month; it considers a number of factors, including exposure to ozone, that in combination increase a child’s risk of autism. Which does make you think again about the autism epidemic in West Hollywood.The cause is as yet unclear, but Los Angeles’s West Hollywood neighborhood has had about three times as many autism diagnoses as would be expected. Already, more than 10,000 people die each day from the small particles emitted from fossil-fuel burning“More than 10,000 people are dying each day from the small particles coming out from fossil-fuel burning,” James Hansen told me, “which is more than have been killed in history from the radiation from nuclear-power plants. It’s an irrational fear of low-level radiation. You have to avoid high levels of radiation, but we know ways to do nuclear which are much safer — that will not explode, that won’t produce a meltdown.” ; each year, 339,000 people die from wildfire smoke, in part because climate change has extended forest-fireThis data is a decade old, and would likely be even higher now. season (in the U.S., it’s increased by 78 days since 1970See here. ). By 2050, according to the U.S. Forest Service, wildfires will be twice as destructive as they are today; in some places, the area burned could grow fivefold.For further reading, see this Forest Service material about the longer fire season. What worries people even more is the effect that would have on emissions, especially when the fires ravage forests arising out of peat. Peatland fires in Indonesia in 1997, for instance, added to the global CO2 release by up to 40 percent,The fires continued into 1998, but the carbon quantification is limited to the previous year; that suggests the estimate is likely too low. and more burning only means more warming only means more burning. There is also the terrifying possibility that rain forests like the Amazon, which in 2010 suffered its second “hundred-year drought” in the space of five years,Obviously, droughts of this scale should no longer, technically, be considered “hundred-year” events. could dry out enough to become vulnerable to these kinds of devastating, rolling forest fires — which would not only expel enormous amounts of carbon into the atmosphere but also shrink the size of the forest. That is especially bad because the Amazon alone provides 20 percent of our oxygen. Not that we’re really at risk of running out of oxygen, even with a significantly diminished Amazon. Then there are the more familiar forms of pollution. In 2013, melting Arctic ice remodeled Asian weather patterns, depriving industrial China of the natural ventilation systems it had come to depend on, which blanketed much of the country’s north in an unbreathable smog.“Today, Shanghai air really has a layered taste,” chef Alan Yu said in 2013. “At first, it tastes slightly astringent with some smokiness. Upon full contact with your palate, the aftertaste has some earthy bitterness, and upon careful distinguishing you can even feel some dust-like particulate matter.” Literally unbreathable.This difficulty was widely reported, but recently China has taken action to reduce its dependence on coal-generated electricity, which will likely help the smog buildup. A metric called the Air Quality Index categorizes the risks and tops out at the 301-to-500 range, warning of “serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly” and, for all others, “serious risk of respiratory effects”; at that level, “everyone should avoid all outdoor exertion.”For more information on the Air Quality Index and what it measures, see here and here. The Chinese “airpocalypse” of 2013 peaked at what would have been an Air Quality Index of over 800.Some of these measures vary a bit. That year, smog was responsible for a third of all deaths in the country.In many cases, the smog exacerbated other medical conditions.

VI. Perpetual War

The violence baked into heat. Climatologists are very careful when talking about Syria.“There’s a lot of qualitative narrative evidence linking climate to the Syrian civil conflict,” Marshall Burke of Stanford’s Earth System Science Center told me. “I think some of that’s compelling. But it’s hard to make a quantitative case for any particular conflict that climate was the cause, right? We don’t observe the Syrian civil war in the absence of the drought that happened in 2007, so we don’t have a good experiment.” Michael Mann, director of Pennsylvania State University’s Earth System Science Center, told me this: “The Syrian uprising was driven by another drought that was the worst drought on record — the paleo record suggests the worst in 900 years. Drought is a big one, it’s behind a lot of the conflict that we see.” They want you to know that while climate change did produce a drought that contributed to civil war, it is not exactly fair to say that the conflict is the result of warming; next door, for instance, Lebanon suffered the same crop failures. Of course there are many negative shocks short of civil war. “In 2012,” Peter Brannen writes in Ends of the World, “when the monsoon failed in India (as it’s expected to do in a warmer world), 670 million people — that is, 10 percent of the global population — lost access to power when the grid was crippled by unusually high demand from farmers struggling to irrigate their fields, while the high temperatures sent many Indians seeking kilowatt-chugging air conditioning.” But researchers like Marshall Burke and Solomon Hsiang have managed to quantify some of the non-obvious relationships between temperature and violence“A lot of folks have looked at these relationships, and they’ve been sort of hypothesized for a long time,” Burke told me. “You can find it as far back as Shakespeare and probably even earlier than that — mentions of linkages between climate and human violence. So there’s this nice part in Romeo and Juliet where the good guys are out in the streets — it’s like Benvolio and Mercutio or something — and they’re talking and one of them says to the other, ‘We should go inside. It’s hot out. We’re gonna get pissed off and things are gonna go badly.’ And then all hell breaks loose. That’s how I start every talk on conflict now. ‘This is the Shakespeare reference.’” He continued: “It’s sort of remarkable how clear and replicable the results have been, when you look over the last 20 or 30 years, periods over which we have sort of better conflict data around the world and can do a good job of sort of understanding statistically what the linkages have been. We can look at different types of conflict, and, depending on where you are, there are certain types of conflict and there aren’t certain types of conflict. The iconic civil-war picture people have in their mind, those unfortunately still occur and tend to occur mostly in places like sub-Saharan Africa. So that’s where a lot of the research there is focused. Of course in the U.S., we don’t have civil wars, or at least not for the last 150 years. But we have other types of human violence, and those are pretty well measured in data and we can study those. And across all these different types of violence, again, we see this strong positive relationship between warmer-than-average temperatures and increasing conflict.” : For every half-degree of warming, they say, societies will see between a 10 and 20 percent increase in the likelihood of armed conflict.“When you increase temperature by half a degree, on average you see something like a 10 to 20 percent increase in the risk of conflict,” Burke told me. “Now, that, of course, does not mean that every conflict has something to do with the climate system. We’re not claiming that every conflict has a climate root. But on average climate has worked, as the CIA says, as a threat multiplier for conflict around the world. This just shows up so strongly in the data that we just can’t ignore it, right? We can’t turn away from this historical fact in the data. Do we fully understand that fact? I don’t think so. There are a lot of different potential mechanisms that could link climate to conflict. But it is in the data. So now I think it’s our job as researchers to better understand what are the exact mechanisms that link these two things. And there are a lot of folks working on that. Our team’s working on it. Other folks are. And we have some ideas. But I wouldn’t say there’s a smoking gun in terms of perfectly understanding the linkage. But to ignore the linkage in the data, to me, would be insane. It’s so strongly there, and comes through in so many settings, that it’s just a statistical fact.” In climate science, nothing is simple, but the arithmetic is harrowing: A planet five degrees warmer would have at least half again as many wars as we do today. Overall, social conflict could more than double this century.To read more of Burke and Hsiang’s work on the relationship between climate and conflict, I recommend these two papers. This is one reason that, as nearly every climate scientist I spoke to pointed out, the U.S. military is obsessed with climate changeIn 2015, the Department of Defense released this major report on the impacts of climate change on national security. : The drowning of all American Navy bases by sea-level rise is trouble enough, but being the world’s policeman is quite a bit harder when the crime rate doubles. Of course, it’s not just Syria where climate has contributed to conflict. Some speculate that the elevated level of strife across the Middle East over the past generation reflects the pressures of global warming“The Middle East, where we’ve also seen a lot of this conflict — I don’t think we can rule out potential effects there, either now or in the future,” Burke told me. — a hypothesis all the more cruel considering that warming began accelerating when the industrialized world extracted and then burned the region’s oil. What accounts for the relationship between climate and conflict? Some of it comes down to agriculture and economics “Hot temperatures reduce agricultural productivity, lower crop yields, and, at the margin for farmers who are close to subsistence, this could alter their incentives to start or join a conflict,” Burke told me. “They need resources. They need to put food on the table. And joining a conflict is one way to do that, as I think a long literature has shown. And, again, it’s not like hot temperature is needed to turn everyone into a civil-war insurgent. These civil wars are often started with very small numbers of people. So you only need to affect the decisions of literally handfuls of individuals to get some of these conflicts.” ; a lot has to do with forced migration, already at a record high, with at least 65 million displaced people wandering the planet right now.See here. But there is also the simple fact of individual irritability. “People are more pissed off on Twitter when it’s hot,” Burke told me. “They use frowny face emoticons more often. People commit aggravated assault and homicide more often when it’s hot in the U.S. This has been show pretty clearly. We have new work showing that people commit violence on themselves more often when it’s hot. So you see rates of suicide go up when temperatures are hot. All sorts of human violence — from an individual scale all the way up to a group-level scale — show an increase when you crank up the temperature. The agricultural stuff I think is a plausible explanation for group-scale violence. It is a less plausible explanation for the individual-level stuff.” Heat increases municipal crime rates, and swearing on social media, and the likelihood that a major-league pitcher, coming to the mound after his teammate has been hit by a pitch, will hit an opposing batter in retaliation.The study on baseball retaliation can be found here, and further interesting research between heat and crime here. And the arrival of air-conditioning in the developed world, in the middle of the past century, did little to solve the problem of the summer crime wave.

VII. Permanent Economic Collapse

Dismal capitalism in a half-poorer world. The murmuring mantra of global neoliberalism, which prevailed between the end of the Cold War and the onset of the Great Recession, is that economic growth would save us from anything and everything. But in the aftermath of the 2008 crash, a growing number of historians studying what they call “fossil capitalism”Andreas Malm’s Fossil Capital is the touchstone. have begun to suggest that the entire history of swift economic growth, which began somewhat suddenly in the 18th century, is not the result of innovation or trade or the dynamics of global capitalism but simply our discovery of fossil fuels and all their raw power — a onetime injection of new “value” into a system that had previously been characterized by global subsistence living. Before fossil fuels, nobody lived better than their parents or grandparents or ancestors from 500 years before, except in the immediate aftermath of a great plague like the Black Death, which allowed the lucky survivors to gobble up the resources liberated by mass graves. After we’ve burned all the fossil fuels, these scholars suggest, perhaps we will return to a “steady state” global economy. Of course, that onetime injection has a devastating long-term cost: climate change. The most exciting research on the economics of warming has also come from Hsiang and his colleagues, who are not historians of fossil capitalism but who offer some very bleak analysis of their ownThey’ve also put together a helpful website exploring and illustrating their findings. : Every degree Celsius of warming costs, on average, 1.2 percent of GDP“You see huge responses in GDP to fluctuations in temperature,” Burke told me. “So in hot countries if you crank up the temperature one degree Celsius you lose about one percentage point GDP growth in that year. Instead of growing at 2 percent a year you’re growing at 1 percent a year. So there’s a huge effect.” The precise 1.2 percentage point estimate for GDP loss is for the United States. (an enormous number, considering we count growth in the low single digits as “strong”“It turns out, historically the optimum temperature for producing things is about 13 degrees Celsius,” Burke told me. “That’s what we see in the historical data. And a couple of the largest economies in the world, coincidentally or not, are right at 13 degrees Celsius. So the annual average temperature in the U.S. is right above. It’s 13-point-something, 13.4 degrees Celsius, which is sort of funny to think about. I live out here in the Bay Area and the annual average temperature in Palo Alto, California, is 13 degrees Celsius. Silicon Valley is at the optimum temperature for producing things as measured historically.” ). This is the sterling work in the field, and their median projection is for a 23 percent loss in per capita earning globally by the end of this century (resulting from changes in agriculture, crime, storms, energy, mortality, and labor).That paper is found here. Tracing the shape of the probability curve is even scarier: There is a 12 percent chance that climate change will reduce global output by more than 50 percent by 2100, they say, and a 51 percent chance that it lowers per capita GDP by 20 percent or more by then, unless emissions decline. By comparison, the Great Recession lowered global GDP by about 6 percent, in a onetime shock; Hsiang and his colleagues estimate a one-in-eight chance of an ongoing and irreversible effect by the end of the century that is eight times worse.You can explore this material more here. The scale of that economic devastation is hard to comprehend, but you can start by imagining what the world would look like today with an economy half as big, which would produce only half as much value, generating only half as much to offer the workers of the world. It makes the grounding of flights out of heat-stricken Phoenix last monthThe science of this is fascinating. A crude summary: Hotter air is less dense, which means less lift for planes trying to take off. (Also interestingly, some models are more effective at higher temperatures than others.) seem like pathetically small economic potatoes. And, among other things, it makes the idea of postponing government action on reducing emissions and relying solely on growth and technology to solve the problem an absurd business calculation. Every round-trip ticket on flights from New York to London, keep in mind, costs the Arctic three more square meters of ice.Which does suggest the wisdom of a carbon tax.

VIII. Poisoned Oceans

Sulfide burps off the skeleton coast. That the sea will become a killer is a given.“People are expecting, depending on what we do, maybe two or three feet in the next hundred years,” Richard Alley told me. “But there’s some chance of 15. If you put that in, that’s one that’s clearly concerning. The worst case you can think of is, you build the levees, you tell people it’s safe, West Antarctic collapses, and the levees fail. There’s a bit of worry about the predictability. If it goes fast — and fast would be decades or less, rather than centuries or more — it will probably involve a lot of breakage, a lot of icebergs breaking off. Fracture mechanics is pretty well understood, but the predictability of it … Just think of all the times in your life that you’ve seen somebody drop a ceramic coffee cup on the floor. Do we understand fracture? Sure. Can you accurately predict what one coffee cup will do when you drop it on the floor? Maybe not.” Barring a radical reduction of emissions, we will see at least four feet of sea-level rise and possibly ten by the end of the century.Ten feet is the upper estimate. A third of the world’s major cities are on the coast,See this paper from Gordon McGranahan, Deborah Balk, and Bridget Anderson. When looking just at extremely large cities — those with populations above 5 million — nearly two-thirds are on the coast. not to mention its power plants, ports, navy bases, farmlands, fisheries, river deltas, marshlands, and rice-paddy empires, and even those above ten feet will flood much more easily, and much more regularly, if the water gets that high.“As the sea level rises, it’s like a diving board for storm surge,” Peter Ward told me. “You’re causing storm surge to jump ever farther inland.” At least 600 million people live within ten meters of sea level today.See, again, the paper from McGranahan, Balk, and Anderson. But the drowning of those homelands is just the start. At present, more than a third of the world’s carbon is sucked up by the oceansEstimates vary from about a quarter to about half; this paper suggests 40 percent of all carbon since the beginning of the industrial era has gone into the ocean. Lee Kump’s estimate is higher: “Half of the fossil fuels we’ve burned have gone into the ocean, which has mitigated the warming,” he told me. Then added: “What are the limits to the Earth’s ability to do that? — thank God, or else we’d have that much more warming already. But the result is what’s called “ocean acidification,” which, on its own, may add a half a degree to warming this century.See here. It is also already burning through the planet’s water basins — you may remember these as the place where life arose in the first place. You have probably heard of “coral bleaching” — that is, coral dyingIn fairness, coral bleaching is not quite a true euphemism for coral dying; when corals are stressed, they expel algae, which turns them white. The corals can recover but often do not. — which is very bad news, because reefs support as much as a quarter of all marine life and supply food for half a billion people.Although some scientists believe there is hope for the reefs. Ocean acidification will fry fish populations directly, too, though scientists aren’t yet sure how to predict the effects on the stuff we haul out of the ocean to eatIf you think about the plankton floating around the ocean, they’re at the base of the food chain,” Lee Kump told me. “There’s a cascade of effects up the food chain that can have impacts on food supply for humans especially — that’s associated with coastal fisheries, that sort of thing.” ; they do know that in acid waters, oysters and mussels will struggle to grow their shells,See here. and that when the pH of human blood drops as much as the oceans’ pH has over the past generation, it induces seizures, comas, and sudden death.This is obviously a very loose analogy, but it’s based on material from the Smithsonian. It’s also not an uncommon one; Lee Kump, too, resorted to the analogy of the human body when explaining to me the principle of ocean homeostasis, and what its disruption might mean. “An underlying theoretical framework for that arises from human homeostatic mechanisms,” he said. “We have homeostatic mechanisms for stabilizing body temperature and all different parts of our physiology.” That isn’t all that ocean acidification can do. Carbon absorption can initiate a feedback loop in which underoxygenated waters breed different kinds of microbes that turn the water still more “anoxic,” first in deep ocean “dead zones,” then gradually up toward the surface.“The other thing we should be watching very closely,” Lee Kump told me, “is the expansion of low-oxygen waters — the so-called dead zones in the coastal ocean, where the drop of oxygen is the combined effect of the warming, because the water can just take up less oxygen.” There, the small fish die out, unable to breathe, which means oxygen-eating bacteria thrive, and the feedback loop doubles back.Research on climate change and dead zones can be found here, and is synthesized here. That paper notes: “Given the variety and strength of the mechanisms by which climate change exacerbates hypoxia” — that’s lack of oxygen — “and the rates at which climate is changing, we posit that climate change variables are contributing to the dead zone epidemic.” This process, in which dead zones grow like cancers, choking off marine life and wiping out fisheries, is already quite advanced in parts of the Gulf of Mexico and just off Namibia, where hydrogen sulfide is bubbling out of the sea along a thousand-mile stretch of land known as the “Skeleton Coast.”Read NASA on hydrogen sulfide and the Skeleton Coast. The name originally referred to the detritus of the whaling industry, but today it’s more apt than ever. Hydrogen sulfide is so toxic that evolution has trained us to recognize the tiniest, safest traces of it, which is why our noses are so exquisitely skilled at registering flatulence. Hydrogen sulfide is also the thing that finally did us in that time 97 percent of all life on Earth died, once all the feedback loops had been triggered and the circulating jet streams of a warmed ocean ground to a haltSee this summary of findings by Lee Kump. — it’s the planet’s preferred gas for a natural holocaust. Gradually, the ocean’s dead zones spread, killing off marine species that had dominated the oceans for hundreds of millions of years, and the gas the inert waters gave off into the atmosphere poisoned everything on land. Plants, too. It was millions of years before the oceans recovered.

IX. The Great Filter

Our present eeriness cannot last. So why can’t we see it? In his recent book-length essay The Great Derangement, the Indian novelist Amitav Ghosh wonders why global warming and natural disaster haven’t become major subjects of contemporary fiction — why we don’t seem able to imagine climate catastrophe, and why we haven’t yet had a spate of novels in the genre he basically imagines into half-existence and names “the environmental uncanny.” “Consider, for example, the stories that congeal around questions like, ‘Where were you when the Berlin Wall fell?’ or ‘Where were you on 9/11?’ ” he writes. “Will it ever be possible to ask, in the same vein, ‘Where were you at 400 ppm?’ or ‘Where were you when the Larsen B ice shelf broke up?’ ” His answer: Probably not, because the dilemmas and dramas of climate change are simply incompatible with the kinds of stories we tell ourselves about ourselves, especially in novels, which tend to emphasize the journey of an individual conscience rather than the poisonous miasma of social fate.In general, I’d say Ghosh is more or less accurate in describing the state of the “climate novel,” though there has been a recent rise in disaster fiction. But he is less on point when talking more generally about our narrative culture; our movies and television, for instance, have been littered lately with apocalypse scenarios, not all climate-related but which can probably be understood as in some ways inflected by climate anxiety. Perhaps a more interesting question is not why we have failed to imagine these scenarios, but why we have quarantined them, culturally, as something like parables, rather than stories that impress on us the real-world urgency of climate change. Surely this blindness will not last — the world we are about to inhabit will not permit it. In a six-degree-warmer world, the Earth’s ecosystem will boil with so many natural disasters that we will just start calling them “weather”: a constant swarm of out-of-control typhoons and tornadoes and floods and droughts, the planet assaulted regularly with climate events that not so long ago destroyed whole civilizations. The strongest hurricanes will come more often, and we’ll have to invent new categories with which to describe them; tornadoes will grow longer and wider“In particular, the trail of destruction from tornadoes may be getting longer and wider,” Joseph Romm writes in Climate Change, summarizing the work of James Elsner. and strike much more frequently,The reaction of tornadoes to climate change is not fully understood, but Michael Tippett of Columbia explains that a warming climate will make the circumstances necessary for tornado formation much more common. In Climate Change, Romm quotes Tom Karl, director of NOAA’s National Climatic Data Center saying “What we can say with confidence is that heavy and extreme precipitation events often associated with thunderstorms and convection are increasing and have been linked to human-induced changes in atmospheric composition.” and hail rocks will quadruple in size.Tippett has published dozens of papers on this subject. Also, see this paper by John T. Allen in Nature on the potential of hail increasing in size and frequency due to climate change. Humans used to watch the weather to prophesy the future; going forward, we will see in its wrath the vengeance of the past. Early naturalists talked often about “deep time” — the perception they had, contemplating the grandeur of this valley or that rock basin, of the profound slowness of nature. What lies in store for us is more like what the Victorian anthropologists identified as “dreamtime,” or “everywhen”: the semi-mythical experience, described by Aboriginal Australians, of encountering, in the present moment, an out-of-time past, when ancestors, heroes, and demigods crowded an epic stage. You can find it already watching footage of an iceberg collapsing into the sea — a feeling of history happening all at once. It is. Many people perceive climate change as a sort of moral and economic debt, accumulated since the beginning of the Industrial Revolution and now come due after several centuries — a helpful perspective, in a way, since it is the carbon-burning processes that began in 18th-century England that lit the fuse of everything that followed. But more than half of the carbon humanity has exhaled into the atmosphere in its entire history has been emitted in just the past three decades; since the end of World War II, the figure is 85 percent.The graph of emissions over time is very vivid. Which means that, in the length of a single generation, global warming has brought us to the brink of planetary catastrophe, and that the story of the industrial world’s kamikaze mission is also the story of a single lifetime. My father’s, for instance: born in 1938, among his first memories the news of Pearl Harbor and the mythic Air Force of the propaganda films that followed, films that doubled as advertisements for imperial-American industrial might; and among his last memories the coverage of the desperate signing of the Paris climate accords on cable news, ten weeks before he died of lung cancer last July. Or my mother’s: born in 1945, to German Jews fleeing the smokestacks through which their relatives were incinerated, now enjoying her 72nd year in an American commodity paradise, a paradise supported by the supply chains of an industrialized developing world. She has been smoking for 57 of those years, unfiltered. Or the scientists’. Some of the men who first identified a changing climate (and given the generation, those who became famous were men) are still alive; a few are even still working. Wally Broecker is 84 years old and drives to work at the Lamont-Doherty Earth Observatory across the Hudson every day from the Upper West Side. Like most of those who first raised the alarm, he believes that no amount of emissions reduction alone can meaningfully help avoid disaster. Instead, he puts his faith in carbon capture — untested technology to extract carbon dioxide from the atmosphere, which Broecker estimates will cost at least several trillion dollars — and various forms of “geoengineering,” the catchall name for a variety of moon-shot technologies far-fetched enough that many climate scientists prefer to regard them as dreams, or nightmares, from science fiction.My full interview with Broecker is here. Among the scientists I interviewed for this story, David Battisti was among the most outspoken about the risks of geoengineering of this kind. “It’s really stupid as an insurance policy — to think it’s anything but a Hail Mary pass,” he said. “This is so obvious to us. I’ve worked on it in the past — you don’t have to do very much to show that it’s dangerous. I’d rather see the world go to four degrees warmer than do geoengineering.” He is especially focused on what’s called the aerosol approachScientists at Harvard have recently launched a new research effort into aerosol injection. — dispersing so much sulfur dioxide into the atmosphere that when it converts to sulfuric acid, it will cloud a fifth of the horizon and reflect back 2 percent of the sun’s rays, buying the planet at least a little wiggle room, heat-wise. “Of course, that would make our sunsets very red, would bleach the sky, would make more acid rain,” he says. “But you have to look at the magnitude of the problem. You got to watch that you don’t say the giant problem shouldn’t be solved because the solution causes some smaller problems.” He won’t be around to see that, he told me. “But in your lifetime …” Jim Hansen is another member of this godfather generation. Born in 1941, he became a climatologist at the University of Iowa, developed the groundbreaking “Zero Model” for projecting climate change, and later became the head of climate research at NASA, only to leave under pressure when, while still a federal employee, he filed a lawsuit against the federal government charging inaction on warming (along the way he got arrested a few times for protesting, too).Including for protesting the Keystone XL pipeline. The lawsuit, which is brought by a collective called Our Children’s Trust and is often described as “kids versus climate change,” is built on an appeal to the equal-protection clause, namely, that in failing to take action on warming, the government is violating it by imposing massive costs on future generations; it is scheduled to be heard this winter in Oregon district court.Go here for more information on the case; it could be hugely significant. Hansen has recently given up on solving the climate problem with a carbon tax alone,The word “alone” has been added to to make clear that James Hansen still supports a carbon-tax-based approach to emissions, even though he no longer believes it will be sufficient. which had been his preferred approach, and has set about calculating the total cost of the additional measure of extracting carbon from the atmosphere. Hansen began his career studying Venus, which was once a very Earth-like planet with plenty of life-supporting water before runaway climate change rapidly transformed it into an arid and uninhabitable sphere enveloped in an unbreathable gas; he switched to studying our planet by 30, wondering why he should be squinting across the solar system to explore rapid environmental change when he could see it all around him on the planet he was standing on. “When we wrote our first paper on this, in 1981,” he told me, “I remember saying to one of my co-authors, ‘This is going to be very interesting. Sometime during our careers, we’re going to see these things beginning to happen.’ ” Several of the scientists I spoke with proposed global warming as the solution to Fermi’s famous paradox, which asks, If the universe is so big, then why haven’t we encountered any other intelligent life in it? The answer, they suggested, is that the natural life span of a civilization may be only several thousand years, and the life span of an industrial civilization perhaps only several hundred. In a universe that is many billions of years old, with star systems separated as much by time as by space, civilizations might emerge and develop and burn themselves up simply too fast to ever find one another.In their paper “Anthropic Shadow,” Nick Bostrom and his colleagues explored our difficulty understanding truly existential risks. Because, by definition, human life has evolved to where it is today in the absence of a species-extinguishing event, we present-day human historians are endowed with enormous, accidental overconfidence in our capacity to endure, they suggest. This is another corollary of the anthropic principle: We take the human experience as our only model of evolution, discounting entirely the infinite number of evolutionary branches cut dead at the nub elsewhere in the universe. “As a consequence,” Bostrom and his colleagues write, “we should have no confidence in historically based probability estimates for events that would certainly extinguish humanity.” Peter Ward, a charismatic paleontologist among those responsible for discovering that the planet’s mass extinctions were caused by greenhouse gas, calls this the “Great Filter”: “Civilizations rise, but there’s an environmental filter that causes them to die off again and disappear fairly quickly,” he told me. “If you look at planet Earth, the filtering we’ve had in the past has been in these mass extinctions.”My full interview with Ward ends with his saying, “Go get ’em, man. We need people out there like you. I mean it. Though you’re not going to get thanked for it, you know.” The mass extinction we are now living through has only just begun; so much more dying is coming. And yet, improbably, Ward is an optimist. So are Broecker and Hansen and many of the other scientists I spoke to. We have not developed much of a religion of meaning around climate change that might comfort us, or give us purpose, in the face of possible annihilation. But climate scientists have a strange kind of faith: We will find a way to forestall radical warming, they say, because we must. It is not easy to know how much to be reassured by that bleak certainty, and how much to wonder whether it is another form of delusion; for global warming to work as parable, of course, someone needs to survive to tell the story. The scientists know that to even meet the Paris goals, by 2050, carbon emissions from energy and industry, which are still rising, will have to fall by half each decade; emissions from land use (deforestation, cow farts, etc.) will have to zero out; and we will need to have invented technologies to extract, annually, twice as much carbon from the atmosphere as the entire planet’s plants now do.This road map was laid out in Science and neatly summarized in Vox. Nevertheless, by and large, the scientists have an enormous confidence in the ingenuity of humans — a confidence perhaps bolstered by their appreciation for climate change, which is, after all, a human invention, too. They point to the Apollo project, the hole in the ozone we patched in the 1980s,The Montreal Protocol, which was finalized in 1987, regulated the use of ozone-depleting substances such as CFCs. Its effects in shrinking the ozone hole began to be measurable in 2000. the passing of the fear of mutually assured destruction. Now we’ve found a way to engineer our own doomsday, and surely we will find a way to engineer our way out of it, one way or another. The planet is not used to being provoked like this, and climate systems designed to give feedback over centuries or millennia prevent us — even those who may be watching closely — from fully imagining the damage done already to the planet. But when we do truly see the world we’ve made, they say, we will also find a way to make it livable. For them, the alternative is simply unimaginable

## Case

Wild

Moon hertiage sites are huge

The link chain is super duper long

Moon basing easier w/ private

Observatory not k2 anything, seeing vocanoes does nothing we alr have satellites