POTENTIATING ALGAE, MODERNIZING BIOECONOMIES:

Algal Biofuels, Bioenergy Economies, and Built Ecologies in the United States and Turkey

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Abstract

This dissertation is an ethnography of potentiation — the labourious processes by which potential is imagined and materialized. It investigates how life scientists and engineers potentiate algae as alternative sustainable biofuels in the wake of the global "food versus fuel debate" of the late 2000s. I draw on two years of multi-sited ethnographic research conducted in the United States and Turkey to document why, how, and to what end do algal biofuel advocates figure algae as a material brimming with "potential." I show that this potential is grounded in the reproductive capacities of algae as a life form, through its activation in environmental remediation projects, and through its compatibility with new biotechnologies and bioeconomic markets. At its heart, this dissertation troubles the notion of potentiality in two ways: it disrupts imaginaries of algae's potential as a "natural," innate sustainable energy resource, while it simultaneously de-naturalizes ideas about the "inherent potential" of the United States as the hegemonic model of all bioeconomies. I begin with a historical overview of biofuels research in the United States and Turkey to demonstrate national differences in algal biofuel advocacy. While state and governmental initiatives profoundly shape algal biofuels research in the United States, the biofuels sector is actively sidelined by the Turkish state. As this dissertation demonstrates, Turkish scientists instead have sought to fill this science and energy policy vacuum by modeling algal biofuels inside their imaginaries of modernity. As such, this dissertation intends to provincialize American-centered accounts of bioeconomies. Further, it contributes to STS literature on bioeconomies by examining how biovalue is made within *systems*, as well as inside of the frameworks of *systems biology* and *integrated systems of production*. By drawing on fieldwork conducted inside laboratories, conferences, and critical textual analyses, I coin the analytic of "built ecologies" — the infrastructures such as test tubes and photobioreactors — to unpack how sustainable algal biofuels are made and remade inside of designed and engineered processes. Challenging these processes, this dissertation instead invites readers to explore alternate ways of engaging with algae and biofuels as a way to confront relentless reductions of life forms into energetic biomass.

Dedication

To my father,

who was a craftsman

Acknowledgments

In closing this chapter of my life, I feel fortunate. Life as a PhD student has been one of the hardest experiences I have ever endured. During this time, I lost my father. Many times, I lost hope in realizing my dream projects in Turkey, especially in these politically precarious times. I was blessed. My supervisor Natasha Myers was always there for me. She reminded me to be hopeful and enthusiastic for my research from the very beginning of our relationship. I first met Natasha seven years ago, while researching the graduate programme in STS at York University. When I left Natasha's office, I was so determined to work with her. I have never regretted it. I left my life in Istanbul behind as I travelled to Toronto in order to work alongside Natasha. I feel that this was perhaps the best choice I have ever made. Natasha helped me cultivate a great enthusiasm for STS and anthropology. There are no words to fully express my gratitude to her. I can only say that, from Natasha, I learned how to care about life, and to care for my work, as well as the work of others. This learning experience has been the most valuable lesson that she has taught me. Thank you, Natasha!

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Chapter I: Introduction

I find myself drawn towards *potential*—the word and what it signals. When I read the news or scientific articles that talk about “potential new energy resources,” such as algal biofuels, I ponder what *potential* means to the authors. I am captivated by stories that figure algae as “miracle cells” and extoll their photosynthetic capacity. And I marvel at the ways that algae is positioned as a sustainable yet modernizing energy source — particularly, one that is seen as more efficient and productive than other biofuel feedstocks, such as corn or sugarcane.

Materiality matters. I gesture here towards the differences between algal and plant-based energy crops. In the midst of a global food crisis, the late 2000s saw tensions between rising food prices and demands for biofuels that coalesced into a “food versus fuel” debate. This debate marked pushbacks against land use practices that were meant to fuel cars instead of feeding people.[1] Many blamed biofuels, especially those produced from corn, for increasing food prices worldwide. This tension peaked in the wake of *The Guardian*’s feature of a “secret report” published by the World Bank.[2] In response to ensuing public outcries, governmental agencies, and biofuel researchers across the globe began mobilizing around alternative biofuel feedstocks, such as plant discards and algae. Among these materials, algae emerged as the most “hopeful” alternative in the “food versus fuel debate” — a sentiment most acutely felt in the United States (Gao et al., 2012). It seemed that algae had the potential to transform the bad reputation of biofuels, and to add more to the bioeconomy by providing other bioproducts, such as vitamins, drugs, and cosmetics, in the replacement of fossil fuel based economies. When I listened stories

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[1] Even, biofuels were objected as a “crime against humanity,” in the words of former UN Special Rapporteur John Ziegler (FSC, 2010: 1). Further, the concept of “agrofuel”—instead of “biofuel”—was adopted by the oppositional groups to draw attention to the utilization of agrarian lands and crops for fuel production.

[2] The report was prepared by the economist Donald Mitchell suggested that biofuels from food crops is responsible for the 75% of the total increase in the world food process. For *The Guardian* article, see Chakrabortty, 2008.

and participated in experiments around "algae's potential" with a material-semiotic mode of attention, I was surprised to learn that there was nothing "natural" about potential.

This optimism for algal biofuels' potential takes three forms. First, algae are seen as a "fast-growing," productive species — they replicate at a speed greater than comparable vegetal-based biofuel crops. Second, algal stories promise a future of sustainable production through environmental remediation. Algae are positioned as biological materials that can absorb higher levels of polluting elements, such as carbon dioxide, nitrogen and phosphorus. They become "good," industrious environmental workers. Third, the knowledges and infrastructures that support algal biofuel development are also quickly proliferating. Technologies that produce next-generation, or "advanced," biofuels are themselves signs of technical prowess and modernization. As this dissertation will demonstrate, these technoscientific processes are labour intensive. That is, scientists, corporations, governments, and civil society organizations in the United States, in particular, work in tandem to make algal biofuels viable. In short, they labour to potentiate algae as a "sustainable energy resource."

This fascination with algae's potential, however, is not universal. Although algal biofuels research and investments are a worldwide phenomenon today, the United States continues to be the dominant and dominating model.[3] This dissertation juxtaposes American approaches to algal biofuel development with research conducted in Turkey — a country whose biofuels sector

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[3] For the map of algal biofuels research and investments, you may visit: http://algaebiomass.org/resource-center/abo-resources/algae-map/ It is not a representative map but the only one provides a sense about the distribution of algal biofuels research and companies worldwide. Further, this map constituted at the scale of nation-states should not mislead international character of algal biofuels sector. An investigation of the global character of algal biofuels through tracing capital investments goes beyond the scope of this dissertation.

occupies a marginal space in its energy and science policies.[4] To date, there is a distinct lack of Turkish political and economic engagement with algal biofuels; neither the government nor private industry investors seem interested. However, *scientific* interest in algae is another matter in Turkey. Cadres of life scientists and engineers are spearheading algal biofuels development. These scientists and engineers embrace the notion of *potential* not only as a technological endeavour, but also as a modernizing project. Their labours make algae matter as the stuff of bioeconomies and as a sustainable way forward for a country in the midst of modernization.[5]

This dissertation is an ethnography of the making of *potential*, what I refer to as a process of *potentiation.* It explores how algae are *potentiated* — how they are activated as compelling, convincing, and efficient — as sustainable energy resources through research and development projects in the United States and Turkey. Rather than introducing a cross-comparative study of these projects, or these distinct countries, which in many ways are incommensurate, my goal is to unravel assumptions around bioeconomies are made. Bioenergy economies hinge on technoscientific practices that "economize life" (Murphy, 2017). By exploring the multifaceted ways that algae are potentiated in the making of bioenergy economies, this dissertation troubles the notion that potential is an innate condition of something; that potential is a natural disposition of a thing or being. I document how algae are potentiated through intensive research and development processes, evolutionary stories, imaginaries of sustainability, and desires for modernity. Broadly, this dissertation documents the stories, experimental practices, and affects

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[4] Chapter Two and Chapter Three juxtapose different cases both from the U.S. and Turkey. Chapter Four rather focuses on the Turkish context in the light of one of the main goals of this dissertation, that is, to render non-Western bioeconomies visible.

[5] See Chapter Four for an extended discussion of discourse of potential and its role in the modernization of Turkey. Recently, discourses of potential are notably used to hail Turkey's untapped growth as a leader in the region. This is evidenced in the Turkish Exporters' Assembly (TİM), and the Turkish Ministry of Economy's joint campaign: "Turkey, Discover the Potential."

that render these organisms into resources for bioenergy economies. When I explore how algal lives get reduced to mere biomass under the rubric of sustainability,[6] I question whether and how alternate sustainabilities can be made imaginable.

The following section begins with a founding story of algae. I introduce the way I learned to see algae, and why I came to be interested in doing research with this organism, positioning this research alongside other multi-species ethnographies. The second section introduces geopolitical and historical contexts for algal biofuels research, and foregrounds integrated systems as an object of study. In the third section, I locate my research and analysis within literatures on biofuels and bioeconomies. I conclude this introduction with a discussion on methodology before introducing the chapters that form the body of this dissertation.

Algae in-the-World, the World in the Algae

Algae are ubiquitous organisms.[7] They are present in almost all of our biosphere's ecologies. Algae can tolerate an impressive array of temperatures and milieus. Some species proliferate on the surfaces moist rocks, stones, timber, and tree trunks. Others inhabit dry soils. Some species are found in deserts, while others flourish in Arctic and Antarctic snows and ice. They mostly, however, thrive in aquatic environments—notably, oceans, rivers, lakes, ponds, streams, and wetlands. They accumulate on the edges of glass aquariums, form pond scum, and drift along on oceanic currents. Algae are all around us. Yet, in many habitats, algae often go unnoticed unless they proliferate massively.[8] A notable example of this phenomenon materializes as "red tides" —

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[6] Biomass refers to the total quantity of specified organisms or organic matter. By the 1970s, the term came to be popularized organic material regarded as a source of fuel (Oxford English Dictionary).

[7] By referring to algae as ubiquitous, I gesture towards anthropological studies that find trivial things important as an ethnographic object (M. Fortun, 2012). For a slightly different take on the notion of "ubiquitous," which refers to the simultaneous universality and uniqueness of the microbial life, see Paxson & Helmreich, 2013.

[8] For a further information on algal habitats, for example, see Graham, Graham, & Wilcox, 2008; Hollar, 2011.

where the overpopulation of a certain species of algae (e.g., *dinoflagellates*) produces potent and visible masses of toxins. Put differently, algae are mostly imperceptible to human eyes until they: (1) cause environmental or health problems, (2) contribute to the well-being of bodies and ecologies, or (3) create economic opportunities as they are processed into commodities, such as biofuels. In this dissertation, I aim to make some these relationships visible. I illuminate how algae come to matter and acquire value in the hands of practitioners who work with them. Through an ethnography of practices and practitioners in science and technology, I explore how life scientists' and engineers' stories and experiments potentiate algae as a sustainable energy resource.

Ethnographic attention to more-than-humans is not new to anthropology or science and technology studies (STS). Recounting early anthropological studies of animals (Morgan, 1868), anthropologists have attended to the lives of animals, plants, fungi, and microbes to show that, "human nature is an interspecies relationship" (Tsing, 2012). By the late 1990s, and alongside social studies of science and political ecologies of biodiversity, ethnographic works on microbial lives, including microalgae, have proliferated (Hird, 2009; Nerlich & Hellsten, 2009; Paxson & Helmreich, 2013; Schrader, 2010, 2012). These studies pay heed to calls for a multispecies ethnography, a theoretical and methodological turn that aims to document "how diverse organisms are entangled in political, economic, and cultural systems" (Helmreich, Kirksey, & Schuetze, 2014: 2). Although documenting non-human agencies has a longer history in science and technology studies (Callon, 1986; Latour, 1987; Mitchell, 2002), multispecies ethnographies embody a different approach towards understanding non-human others. Instead, they focus on the co-production of humans and more-than-humans in what Donna Haraway has called "becoming with" (2008). Drawing from the question of what human beings are becoming (e.g., Wolfe, 2012) to the co-production of knowledge with different species (e.g., Hayward, 2010), multispecies ethnographies trouble anthropocentric epistemologies by suggesting that human beings are not the only actors whose stories are worth telling.

This literature helped me begin my research with the premise that algae are central, crucial, and potent agents in the making of bioenergy economies. The more I attended to scientists' work with algae, the more I became curious about how algae are made potent. Through listening my interlocutors' stories about algae, and observing their experimental practices, the relations between scientists and algae revealed that algae's potential was not innate. During fieldwork, I learned to see how algae are potentiated, activated, and made compelling in the hands and imaginaries of biofuels practitioners. I wanted to understand *why, how, and to what end* are algae potentiated as an energy resource with the promise of sustainability. More precisely, I first needed to understand why I was so concerned about algae. During my research, I became known as the "algae-person" among my interlocutors and academic colleagues. I found myself motivated to conduct research on algae since I, like my scientist interlocutors, deeply care for our planet. It took time, however, to transform this care into a series of critical questions.

As a researcher, I am potentiated alongside my interlocutors and algae. Occasionally, I shared my interlocutors' excitement about algae and embraced their outlook. However, most of the time I felt like an outsider to their research. This feeling of discomfort was two-fold: (1) I had stepped into laboratories and read scientific articles without having prior expertise in algae; and (2) my concerns about sustainability at the intersection of ecologies and economies did not easily translate into readily articulated, critical questions about algal biofuels. In time, however, I learned to read, listen, and observe how scientists worked with algae. Their forms of knowing, experiments, feelings, and motivations all came to matter for me as I explored *how and why they* *engaged with algae*. It also took time to recognize my own positionality as I located myself in the world of algal biofuels research. It all began at the moment I learned that algae have the potential to produce sustainable biofuels.

November 2012. It was a typical chilly evening in Toronto. Inside of my apartment, I was surfing several biofuels websites to monitor recent developments in the industry. It had been approximately three years since the last time I had read about the subject. During my search, I came across the new term, "next-generation biofuels." It was surprising. Until this moment, my knowledge of biofuels was limited to the use of agricultural crops as fuel feedstocks. I naively asked myself: how are alternatives created in capitalist systems? As I read on, I was drawn to the ways algae were promoted as alternative fuel feedstocks. The emphasis on "fast growing and enduring organisms" and their "evolutionary role" grabbed my attention. In light of these claims, I felt that "algae" would be a good object to think with. I followed my intuitions and came to see algae as world-making organisms. In the following section, I introduce you to algae; or more precisely, I outline how I have worked with algae in this dissertation.

Beings

What are algae? Phycologists, the scientists who research algae, have noted the difficulty of defining algae. We learn from these scientists that algae do not form "cohesive group[s]" (Graham, Graham, & Wilcox, 2009: 8).[9] Phycologists instead draw our attention to the systematics of algae; that is, they study algal groups, or clades, on the basis of evolutionary and phylogenetic relations. Furthermore, phycologists emphasize that algae appear to have multiple origins of replication that are not tied to a unique "hypothetical common ancestor" (ibid.).

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[9] Also, see Bhattacharya, 2003; Brodie & Lewis, 2007.

Nevertheless, these scientists classify algae into taxonomic groups on the basis of morphological, reproductive, and biochemical characteristics.[10]

Algae are remarkably diverse organisms.[11] Some scientists claim that 30,000 to one million species of algae exist on Earth (Guiry, 2012), while others propose that a more accurate representation is closer to ten million species (Norton, Melkonian, & Andersen, 1996). Diversity comes not only in quantity, but also in size. Researchers have also noted that algal species range from microscopic single-celled species "[smaller than] one micrometer in diameter to giant seaweeds over 50 meters long" (Graham et al., 2009: 1).[12] They present an array of colours ranging from green, brown, red, yellow, cyan, and golden — colours that alternate according to each organism's production of chlorophylls and associated accessory pigments.[13] Some species, however, can also be transparent (ibid: 11). Furthermore, algae take on different shapes. Several form filaments with cells joined from end to end, some clump together and form colonies, while others drift independently from each other. Algae also reproduce via diverse methods. Particular groups may multiply asexually, including fission or simple cell division; another species may

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[10] In biology, taxonomy is a systematic classification of living organisms to name, describe, and classify organisms according to observed specific characteristics of these organisms (Oxford English Dictionary). The classification of algal species is still in-the-making; *AlgaeBase*—the world-wide electronic publication—is the largest database of information on algae. STS scholarship and anthropology have largely discussed classification systems as epistemology and practice (e.g., Bowker & Star, 1999; Ritvo, 1998). Taxonomy as an object of analysis goes beyond the scope of this dissertation.

[11] I do not approach "biodiversity" as an analytic and/or object of study in this dissertation. I underline the diversity of algal world here to contextualize algal biofuel researchers' emphasis on the "abundance of algae" considered as "advantageous." As I will explore in the following section, algal diversity itself constitutes one of the main challenges in algal biofuels research.

[12] The species *Prochlorococcus* is considered to be the smallest and most abundant algal species, only 0.6 microns.

[13] Plants, algae, and cyanobacteria all contain chlorophyll molecules, which are identified in six different forms (*a, b, c, d, e,* and *f*) and differentiated according to the absorption of different wavelengths. Chlorophyll *a* exists in all photosynthetic cells and converts solar energy into chemical energy, while other forms of chlorophyll molecules work as accessories and transfer energy to chlorophyll *a*. Different chlorophyll molecules are called colour pigments, since they reflect different wavelengths to appear as different colours in sunlight (Campbell, Reece, Taylor, Simon, & Dickey, 2009).

undergo sexual reproduction — producing gametes that combine with the gametes of the opposite sex — while others perform different reproductive processes.

Despite their impressive variability, scientific discourses have often rendered these organisms into a singular form of life writ large. In other words, distinctions between algal species may be overlooked in favour of searching for commonalities. Following Star and Griesemer (1989), I argue that algae are *boundary objects*: (1) they are "plastic enough" to be defined in particular ways according to local purposes, and (2) they are "robust enough" to share a common identity across different contexts (ibid: 393). During my research, I discovered that "algae," as an undifferentiated category, are often positioned as a *singular,* ideal, and sustainable source for biofuels. By this, I mean that a common term "algae" is employed to encapsulate diverse algal species into a singular grouping.[14] Further, it vernacularizes a distinction between algae and bacteria that are capable of photosynthesis from other photosynthetic organisms, namely plants such as corn, sugarcane, and wheat. Thus, although they are distinct organisms, microalgae, macroalgae, and cyanobacteria all fall under the umbrella of "algal biofuels." This lumping together of organisms led me to see that any taxonomic differences or disputes largely disappear when discussing algae's potential and performance as a biofuel (DOE, 2010: 8).[15]

When it comes to algae, I argue that distinctions matter, both materiality and figuratively. In her article on the toxicity of an algal species (*Pfiesteria piscicida*), STS scholar Astrid Schrader (2010) highlights the "ontological indeterminacy" of this species. She differentiates

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[14] I draw attention to this distinction in order to highlight the problems of taxonomic orderings, while attempting to avoid the same trap of reproducing blanket categories. For the sake of writing convention, however, I speak of these categories in the shorthand of "algae."

[15] The term cyanobacteria itself emerged in the 1970s when controversies over the classification of blue-green algae (now, cyanobacteria) ended up with the suggestion that this organisms "really resembles in overall features, the genetic map of *Escherichia coli* [a form of bacteria]" (Margulis, 1977: 83). I interpret the inclusion of cyanobacteria in the definition of algal biofuels—regardless of the debates over its place in bacteria or algae groups—as a strategy to popularize, and thus, potentiate a form of biofuels produced via organisms that are different than plant crops.

ontological indeterminacy from epistemological uncertainties that "refer to 'gaps' in or incompleteness of human knowledges" (Schrader, 2010: 283). Her analytic draws attention to the indeterminacy between *Pfiesteria's* beings and doings, "which is not resolved but affirmed as entanglement" (ibid: 299).[16] By employing the notion "entanglement," Schrader contemplates *Pfiesteria's* beings and doings as "intra-acting 'components,'" which are "inseparable in space and time" (ibid: 285). Schrader's framework helped me ask: how do algae's beings, their ecological and energetic bodies, come to be linked to algae's doings, that is, how they produce oxygen, matter, and energy? In Chapter Two, I will explore how algae's rendering as a photosynthetic organism on a planetary scale gets linked to algae's production of materials at the cellular level. In Chapter Three, I will elaborate on this line of analysis by exploring how imaginaries of sustainability and the design of *integrated production systems* convert these materials into what comes to be known as "sustainable energy resources."

For researchers working on algal products, the biochemical composition of algal bodies is of utmost importance. Researchers choose to work with particular algal strains.[17] This decision is influenced by a strain's metabolic activities, as well as their capacity to accumulate materials with nutritional, medical, or energetic "benefits" in the form of food or food supplements, fodder, fertilizer, or fuel. During fieldwork, I found my attention drawn towards what algae become in the hands of practitioners. I was intrigued by how algal strains become isolated and cultured in artificial environments for research and development purposes. As a result, this ethnographic

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[16] Schrader explores the question of whether *Pfiesteria* can be considered as the "causative agent" of massive fish kills; and, troubles conventional thinking of "cause and effect" that connects independent events in linear time. She seeks to show *Pfiesteria*'s material agency, that is, their contributions to their own materializations: they "co-produce and transform 'themselves' in relation to 'their' environment" (Schrader, 2010: 283-284). Further, for her, ontology is *phantomatic:* "A move from 'being' as a ground in ontology towards a phantomatic ontology…is not a move from 'being' to 'doings' or 'becomings', rather their relationship itself remains inherently indeterminate and must be reconfigured in every intra-act through specific matters of concern" (ibid: 299).

[17] "The term *strain* is commonly used to denote a pure culture" (Dijkshoorn, Ursing, & Ursing, 2000).

study of the experimental lives of algae focuses on how algal beings and doings are domesticated in laboratory settings in the form of models, materials, and technologies. I explore how practitioners' metaphors, knowledges, techniques, technologies, and affects entangle algae's beings and doings in biofuels research. The following section examines what an ethnographic investigation of algal "doings" might look like.

Doings

Algae are photosynthetic organisms. As algae photosynthesize, they participate in a process known as biogeochemical cycling; it is "the movement and exchange of both matter and energy between the four components of the Earth." These components are the atmosphere, the hydrosphere, the lithosphere, and the biosphere (Barsanti & Gualtieri, 2005: 159).[18] For example, in the eyes of scientists, oceanic single-celled algae become floating "invisible forests" that are responsible for almost half of the oxygen-carbon cycle on Earth (Chisholm, 2011). I treat these cybernetically inspired ideas about cycles as tropes that shape the stories scientists tell about algal photosynthesis. Machinic metaphors are also ubiquitous. For example, oceans are figured as "photosynthetic machines." I explore how machinic "renderings" functionalize and instrumentalize algae's photosynthetic potential in ways that naturalize algae as mechanized, manipulable, and labouring organisms (Myers, 2015). In the following chapters, I will demonstrate that this vision of algae as a photosynthetic organism is not a mere appreciation of algae's labours in the maintenance of life. Instead, it is the reduction of algae's beings and doings to the functional and instrumental roles they play in bioenergy economies.

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[18] The atmosphere is "the air envelope that surrounds the Earth"; the hydrosphere "includes all the Earth's water that is found in streams, lakes, seas, soil, groundwater, and air); the lithosphere is the "solid inorganic portion of the Earth, including the soil, sediments, and rock that form the crust and upper mantle"; and, the biosphere refers to "all the living organisms, plants, and animals" (Barsanti & Gualtieri, 2005: 159).

Further, studies of algae explore the flow of chemical elements in and through their bodies. This discourse of flows and cycles also emphasizes the major elements that largely compose algal bodies — namely, carbon (C), oxygen (O), hydrogen (H), nitrogen (N), sulfur (S), and phosphorous (P).[19] In this regard, algae can be considered "elemental rearrangers" (cf. Myers, 2016b). However, rather than being extolled as active organizers of elements on a planetary scale, algae are often reduced to resources or technologies. For example, algae are frequently positioned as the elementary "building blocks" of the marine food chain (Graham et al., 2009: 3-4). This vision of algae is not neutral. In this dissertation, I study how algae concurrently appear as food, fuel, and technologies within biofuel production systems. These mobilizations reveal how algal labour gets naturalized in bioenergy economies.

A common refrain in scientific papers and in the media is that fossil fuels are the derivatives of ancient algae deposits.[20] These stories suggest that like "ancient algae" — that is, dead algae that constitute present-day fossil fuels — living, or "modern algae," can also used as fuel, albeit with notable differences. By creating a continuum that links various forms of algae with energy use over time, an economic rationale naturalizes algae as elemental biomaterials. In other words, in both fossil fuel and biofuel production, these organisms are envisioned as the building blocks of energy itself. As Chapter Two will discuss, algae are thus no longer organisms, but biomaterials that can be cultivated and accumulated as biomass.

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[19] "In total, 99.9% of the biomass is account for by [these] six major elements…The remaining elements [calcium (Ca), potassium (K), sodium (Na), chlorine (CI), magnesium (Mg), iron (Fe), and silicon (Si)] occur chiefly as trace elements, because they are needed only in catalytic quantities" (Barsanti & Gualtieri, 2005: 160).

[20] "The oil we currently exploit comes from Cretaceous deposits of marine algae"—and, "[a]s we use up the oil deposits provided by ancient algae, we are turning the modern algae for help" (Chapman, 2013: 12).

In this dissertation, I aim to make algae's doings visible through an ethnography of what I call *built ecologies.*[21] Built ecologies are designed to operate both inside of laboratories, as experimental containments, and outside, as photobioreactors. I show how built ecologies are world-making infrastructures. I use this analytic to understand how researchers experimenting with algal reproduction render these organisms into energy resources. In Chapter Two, I examine these processes in action. I do so by demonstrating how built ecologies render algae's ecological role of carbon-dioxide absorption into a technical matter of waste remediation, and algal photosynthesis as carbon storage technology. My investigation of built ecologies, therefore, takes its inspiration from science and technology studies of "containers" used in scientific experiments (e.g., Kohler, 1994; Murphy, 2017), and expands on this model to understand how built ecologies potentiate organisms as sustainable energy resources.

Experimenting with Algae Towards "Sustainable Energy Futures"

This dissertation explores the experimental lives of algae through researchers' interventions with these life forms in the making of biofuels. The algal biofuel production process is composed of four main steps: (1) selecting algal strains to be utilized; (2) cultivating algal biomass; (3) pre-processing (e.g., harvesting); and (4) conversion of biomass to fuels (and/or, related bioproducts). Each step enrolls different sciences, knowledges, technologies, techniques, materials, and infrastructures.[22] By analyzing this process, I will demonstrate that strain development and cultivation are crucial instances through which algae's *photosynthetic potential*

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[21] I introduce how ecologies are constructed in laboratory spaces in Chapter Two. In Chapter Three, I expand on how built ecologies operate larger systems of production design—notably, as part of waste streams and integrated systems. These, I argue, form the basis of a much broader practice of world making.

[22] The present state of research on making biofuels via algae is broad and complex enough that I cannot fully document—in order to critically analyze *resource-making process* via algae—within the scope of this dissertation. For a recent comprehensive work that maps out the state of algal biofuels research, see DOE, 2016.

is rendered into its potential economic value. Stated differently, it is in these moments that researchers potentiate algae as “efficient,” “productive,” and “sustainable” biofuel sources. For example, researchers can genetically manipulate algal strains to produce more oil, and optimize algae’s reproductive capacity through biomass cultivation systems.

STS scholars have largely explored the creation of economic value out of biomaterials through their economization, capitalization, or commodification. These studies mostly focus on manipulation, fragmentation, and extraction processes to explore how life forms become commodities and technologies through molecular techniques, such as synthetic biology (e.g., Franklin, 2007; Landecker, 2007; Shukin, 2009; Waldby & Mitchell, 2006). In this ethnography, I draw attention to another economization process, one that is based on systems thinking. I show how integrated systems thinking and design processes render algae into valuable biomaterials that can be commodified. By integrated systems, I refer to both (1) a systems biology approach to algal (biofuels) research, as well as (2) biofuels production system designs that are coupled with processes such as wastewater treatment and carbon dioxide absorption processes.

Chapter Two explores how a systems biology approach brings algae’s “ecological functions” (e.g. carbon dioxide absorption) together with the matter and energy that algae produce (e.g. lipids). Chapter Three investigates the relationship established between algae’s ecological and economic values by focusing on the design and engineering of biofuel production systems. It is through systems design that algae are potentiated not only as biomass, but also as bioremediation technologies. In this sense, what makes algae a sustainable energy resource is not their “natural” photosynthetic potential, rather that this potential is designed and engineered. My investigation, therefore, centers on a critical analysis of systems thinking to contribute new insights into sustainability discussions.

Context

What geopolitical circumstances led to the rise of algal biofuels research? The algae-based biofuels were first conceived in the 1950s through a study of small-scale algae-based methane production at the University of California, Berkeley (see Oswald & Gouleke, 1960). This project supported dominant scientific discourses at the time, which suggested that "photosynthetic processes such as algal systems may not be justifiable if used solely as large-scale energy plantations" (Goldman & Rhyter, 1977: 367). Further, the proposal was linked to a post-World War II paradigm where energy conservation programs, including wastewater treatment, were favored.

By 1978, biochemist John Benemann and his colleagues prepared a landmark report for the U.S. Department of Energy. *Engineering Design and Cost Analysis of a Large-Scale Microalgae Biomass Systems* proposed that large-scale algal systems could produce methane gas at prices competitive with projected fossil fuel costs. In the same year, President Jimmy Carter launched the Aquatics Species Program (ASP) — the first large-scale, government-supported algal biofuels research and development project in the United States. In the wake the early 1970s Middle East oil embargo, algal biofuels projects attracted serious attention as key alternative fuel sources for decreasing dependence on foreign markets.

The U.S. Department of Energy's Office of Fuels Development funded the ASP.[23] The main objective of the ASP was "the production of biodiesel from high lipid-content algae grown in ponds, utilizing waste CO_2 from coal fired power plants" (Sheehan, Dunahay, Benemann, & Roessler, 1998: i). Research activities were mostly carried out by National Renewable Energy Laboratory (NREL) researchers at the labs in Golden, CA, alongside "subcontracted research and development activities conducted by private companies and universities around the country" (ibid).[24] These earlier experiments projected algal biodiesel production costs twice as high as contemporaneous petroleum diesel fuel costs—even after accounting for aggressive developments in algal breeding programs (ibid: 13). Although some note that the program ended in 1996 over concerns of algal biodiesel pricing, I speculate that governmental support for corn-based bioethanol production played a major role in the closure of the ASP. I posit this assumption on the basis of insights garnered in the program's closeout report. This speculation makes sense when I attend to the U.S. government's renewed interest in algal biofuels research and development in 2007, after corn and other biofuel sources had been problematized in the food versus fuel debates.

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[23] The DOE funded the program through the Solar Energy Institute (SERI) in Golden, CO—which became the National Renewable Energy Laboratory (NREL) in 1991. SERI was a "first-of-its kind federal laboratory dedicated to the development of solar energy. The formation of this lab came in response to the energy crises of the early and mid 1970s. At the same time, the Carter Administration consolidated all federal energy activities under the auspices of the newly established U.S. Department of Energy (DOE). Among its various programs established to develop all forms of solar energy, DOE initiated research on the use of plant life as a source of transportation fuels...The Aquatic Species Program (ASP) was just one component of research within the Biofuels Program [now, relatedly, Advanced Algal Systems Program]" (Sheehan et al., 1998: 1). Today, the Office of Fuels Development is known as the Bioenergy Technologies Office under the Office of Energy Efficiency and Renewable Energy.

[24] In the first phase of the ASP, researchers collected algae from "sites in the west, the northwest, and the southeastern regions of the continental U.S., as well as Hawaii": "At its peak, the collection contained over 3,000 strains of organisms. After screening, isolation and characterization efforts, the collection was eventually winnowed down to around 300 species [oil producing microalgae], mostly green algae and diatoms" (Sheehan et al., 1998: 11). Today, the University of Hawaii holds this collection. The second phase of the program focused on the biochemical and physiological studies of collected algae on the basis of their lipid production. Lastly, researchers employed techniques of molecular biology and genetic engineering to increase the productivity of algal lipid production.

Established under the U.S. Energy Independence and Security Act of 2007 (EISA), the Renewable Fuels Standard (RFS) mandate paved the way for the potentiation of alternative source of biofuels that did not compete with agricultural crops. The RFS mandate limited the amount of corn-based bioethanol that could be blended with conventional transportation fuels to 15 billion gallons by the year 2022 out of a total of 36 billion gallons of renewable fuels (DOE, 2016: 1). Although the EISA revitalized scientific and commercial interests in algal biofuels, algae did not gain considerable popularity until May 2009 when U.S. President Barack Obama and U.S. Secretary of Energy Steven Chu announced the investment of $800 million in new biofuels research as part of the American Recovery and Renewable Act.[25] At the time of writing, the DOE has largely revived its investment in algae-based biofuel research, development, and deployment alongside the continued support of the Obama Administration.[26]

The DOE Bioenergy Technologies Office (BETO) continues to play a significant role in the potentiation of American algal biofuels research today. The BETO organizes workshops, and develops strategies to make "sustainable and economical algal biofuels" (DOE, 2016). Its mandate, in this regard, is to be more than a funding agency or legislative mechanism. Non-governmental organizations, like the Algal Biomass Organization (ABO), also contribute to the expansion of algal biofuels research. More, the number of companies investing in American algal biofuels research continues to increase. In the U.S. context, the American state, private investors, and scientists work in tandem to make algal biofuels a viable energy source for consumption in

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[25] "This announcement included funds for the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy's (EERE) Biomass Program [now, The Bioenergy Technologies Office (BETO)] to invest in the research, development, and deployment of commercial algae-to-biofuel process" (DOE, 2010: ii). Further, the question how algae get potentiated through legal instruments goes beyond the scope of this dissertation. The legislative environment that regulates and supports algal biofuels is not limited to the DOE's jurisdiction. For a further information about the policy environment related to algal biofuels, for example, see Trentacoste, Martinez, & Zenk, 2015.

[26] The support for algal biofuels may change within the context of Trump Administration, by taking into consideration of new administration's fossil fuel based energy policies.

the domestic market. As I explore in Chapter Four, the same cannot be said of the Turkish case, where algal biofuels research flourishes despite the absence of state partnerships and private investors.

The pervasiveness and historical trajectory of algal biofuels research in the U.S. has found its way into Turkey. Such as, any history of biofuels in Turkey, by extension, must attend to this context. Therefore, the necessity and utility of conducting fieldwork in the United States became evident. While at MIT, and already in the process of doing participant-observation in an algae laboratory, I spoke to a friend regarding my Masters research. She had been planning to work on Turkey's Konya Sugar Company for her dissertation. Konya Sugar was the lead protagonist in my Masters thesis on sugar beet production.[27] After speaking with my friend, I learned that this company was exploring algal biofuels as a future area of investment. Two weeks' later, I found myself trying to see how I could extend my research to Turkey, and what this could add to my experiences at MIT.

My interlocutors taught me much about the Turkish biofuels sector. It was almost impossible to follow developments in Turkish biofuels on my own, given that (1) biofuels are not addressed in public discussions, and (2) the legal structure for biofuels is constantly changing. Biofuels, I thought, were absent from Turkish renewable energy policies. What I learned, however, was that biofuel research and development was obscured from view. Once I attuned myself to the politics of biofuels sector, I saw that many different actors were indeed working on

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[27] Intriguingly, my engagement with Konya Sugar continued as I found myself drawn back into conversation with her. Notably, it was at Konya Sugar that I was first exposed to biofuels. At one of their factories, I was able to visit several biofuel production facilities. During this visit, I was fascinated by scientists' work there; here, I realized that agriculture encompassed multiple actors beyond farmers, corporations, the state, civil society organizations, and grassroots movements. At the time, I was a Masters student in a joint history and sociology program. My naïve questioning of the roles of scientists and technologies in the shaping of agriculture led me to the Science and Technology Studies (STS) programme at York University. Now, as a doctoral student in STS, I found myself drawn back to Konya Sugar.

algal biofuels – these actors ranged from scientists in aquaculture and fisheries department, biology, to environmental engineering, and even machine engineering. Perplexed, I asked: how do sectors like biofuels development flourish despite the lack of governmental initiatives, like those found in the United States?

When I began fieldwork in 2014, there were no conferences on algal biofuels. During my research, they began to proliferate. Similarly, although Konya Sugar's research into biofuels could be considered as an exceptional case in 2014, this landscape was also shifting. Whenever I encountered an industrial actor interested in algae, I learned that their engagement was based on scientists' invitation to participate in their projects. It was scientists rather than the state or private industry that pushed for algal biofuels in Turkey. In Chapter Four, I investigate why and how scientists embraced algal biofuels despite a political economic vacuum taking place in Turkish renewables policies. As such, this chapter introduces modernization as a context to understand this vacuum.

Overall, sustainability, as a contextualizing force, cuts through my research in the U.S. and Turkish contexts. I examine how sustainability takes shape in desires and imaginaries about the future, how it is figured at the scale of experiments, and how it is framed in distinct geo-political contexts and political economies.

Sustainability

Until the nineteenth century, *sustainable* meant anything that is "bearable" (Oxford English Dictionary). Developed alongside ideas of economic growth and of ecology, sustainability took on a new life in the 1960s as it began circulating in the field of economics and ecology—most notably as an approach to the management of wild species and ecosystems.[28] With the Brundtland Commission's definition of "sustainable development" in 1987,[29] sustainability has become a buzzword used across several domains of life and work, from engineering, to architecture and design, to energy and ecology. Although both advocates and critics of sustainable development have widely debated the Commission's lack of specificity in defining *exactly what sustainability is*, it did pave the way for the emergence of a wide range of practices and ideologies about what sustainability *could be*. The concept further acquired undeniable prevalence by the 1990s, when it was championed at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro.

Critical studies of sustainability discourse have largely discussed, for example, the correlation between the rise of neoliberalism and the claim for sustainable development (see McManus, 1996; Escobar, 1996). In line with these critiques, social scientists coined the term "green-washing" to draw attention to the capitalist embrace of sustainability—that is, the promotion of environmental and ecological branding in order to increase profit margins (Robinson, 2004). Despite these critiques, many scholars suggest that sustainability narratives cannot be reduced to a capitalist logic, and instead claim that "the discourse of sustainability is part of the process of working towards sustainability" (Fricker, 1998: 374). These scholars and activists suggest that we could activate the concept of sustainability by refashioning its surrounding discourses and practices without reducing it into economic terms. According to

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[28] For example, see the definition of "sustainable growth" in The McGraw-Hill Dictionary of Modern Economy. Also, for ecological texts, see, Rachel Carson's *Silent Spring* (1962) and Meadows et al.'s *The Limits to Growth* (1972). Yet, these works do not by themselves "account for the emergence of the 'sustainable development' discourse associated with the Brundtland Commission" (McManus, 1996: 49).

[29] The Brundtland Commission (also known as The World Commission on Environment and Development) was established in 1983 by a resolution of the United Nations General Assembly. The resolution acknowledged that economic development was posing environmental problems and urged to ensure "sustainable development."

some, sustainability can be understood through three interlocking pillars of thought: (1) "economic sustainability," (2) "social sustainability," and (3) "environmental sustainability" (Adams, 2006).

This dissertation explores how sustainability discourses shape my interlocutors' work on and with algae, as well as how their designs of algal biofuel projects make sustainability. This stands at the center of Chapter Three. My aim is to explore how sustainability is constrained, contained, embedded in algal biofuels production systems that integrate wastewater treatment and carbon absorption processes.

Potentiating Algal Biofuels for Bioenergy Economies

To untangle the complexity of organism-biofuels relations, I turn to several literatures on bioenergy and its production. Critical social science literature on biofuels, for example, mostly focuses on the uses of agricultural crops for fuel production.[30] Scholars have largely explored unequal socio-cultural and political economic relations that shape, and are shaped by, the uses of agricultural lands for fuel production (e.g., Biello, 2011; Dauvergne & Neville, 2010; Hunsberger, 2014). These literatures reference themes of land grabbing, colonialism, global North-South relations, and social movements among others (e.g., Borras, Franco, & Wang, 2013; McMichael, 2009, 2010; White & Dasgupta, 2010). Other studies, such as political ecology, have explored the environmental impacts of biofuels, including concerns over deforestation and biodiversity loss (e.g., Baka, 2014; Balkema & Pols, 2015; Hunsberger & Ponte, 2014). Although these discussions inform this dissertation, my aim is to develop an ethnographically informed STS perspective specific to critical biofuels studies. I do so by focusing on

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[30] For an introduction to this line of discussions, for example, see, "The Special Issue 4—Biofuels, Land, and Agrarian Change," published by the *Journal of Peasant Studies* (Vol. 37, 2010).

experimental research activities and infrastructures that render algae into biomass for energy production.

STS scholar and sociologist Adrian Mackenzie (2013) has approached "next-generation" biofuels as a case study through which to broadly rethink the relation between sciences and technologies, while focusing on synthetic biology, in particular. For Mackenzie, biofuels are the "industrial face of synthetic biology." Further, he examines the entanglements of synthetic biology and commerce when he asks: "is the whole field of synthetic biology shaped, more or less implicitly, by economics?" (Mackenzie, 2013: 190, 192). Centering on the "technicity" of research undertaken by several American biotech firms, Mackenzie proposes that synthetic biology work on biofuels "co-emerges" with new market regimes rather than being a science shaped by external commercial pressures (ibid: 196).[31] Mackenzie's discussion provides a fresh look at STS-inflected biofuels research. What I want to add to this approach is the insistence that technological claims about so-called "next-generation" biofuels cannot be taken at face value. My research shows that technoscientific discourses and practices around algal biofuels must be examined through a culturally-informed lens in order to understand the making of bioenergy economies. I do this by examining the cultural specificity of the ways in which they unfold differently in American and Turkish contexts.

While STS scholars have only begun to analyze biofuels, there is an extensive literature on bioeconomies from which to start exploring the technoscientific discourses and practices around them. Rather than "thinking with biofuels" to understand how bioeconomies are formed, this dissertation intends to develop new perspectives on the political economy and ecology of

[31] By market regimes, he refers to supply chain management, in which technology is not necessarily used to "intensify the process of production and circulation of commodification at ever more competitive prices," but rather that this technology "is meant to inject disruptive, revolutionary or 'game-changing' shifts in the nature of commodities." (Mackenzie, 2013: 195).

biofuel relations. The following chapters will build on this aim in order to establish an ethnographically-grounded, STS analyses of algal bioeconomies. I will then turn to the different ways in which bioenergy economies take shape in the context of Turkish and American algal biofuels projects.

Bioeconomies

In 2005, the Organization for Economic Co-operation and Development (OECD) first coined the term, "bioeconomy." According to this definition, the bioeconomy makes up that part of economic activities that harness the "latent value in biological processes and renewable bioresources to produce improved health and sustainable growth and development" (Cooper, 2008: 45). While initial definitions of the bioeconomy were equated with the production of "sustainable biofuels and bioproducts," it came to signify more than biofuels.[32]

STS scholars have explored bioeconomies to demonstrate the intense traffic between the life sciences and capitalism (Cooper, 2008).[33] These scholars have traced the emergence of the bioeconomy as a practice that goes back to the 1980s—an era that witnessed the simultaneous rise of neoliberal economies, ecological modernity, and a biotechnology-based industry. These scholars developed new analytics to examine forms and processes of the economization, capitalization, and commodification of life, including the concepts of "biocapital" (Sunder Rajan, 2006), "biovalue" (Waldby & Mitchell, 2006), "blue-green capitalism" (Helmreich, 2009), and "surplus life" (Cooper, 2008). These scholars have examined a range of issues, including the instrumentalization of biomaterials, legal and laboratory practices, and speculative nature of

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[32] For a changing definitions of the bioeconomy in policy documents, see: Goven & Pavone, 2014.
[33] Each chapter provides the related literature review on bioeconomies.

economies shaping life sciences. The literature has also shed light on how economic logics figure the life sciences.

At the core of this literature lies a critique of STS scholarship — that is, the neglect of an analysis on the political economy of the sciences. This critique challenges scholarship that singularly attends to micro-level studies of scientific knowledge production that overlook "institutional or structural contexts" of biofuel production (Goven & Pavone, 2014: 325). For example, STS scholar Kean Birch has developed his research on biofuels and bioeconomies to redirect STS's attention to political economic actors' knowledges and practices. He advances a "macro-level" analysis of financialization, capitalization, and assetization to understand the valuation of biological processes. And yet, as my ethnographic research shows, the political economy cannot be reduced to the "macro-level" studies of institutions, for example. For me, a political economic analysis of biofuels requires ethnographic attention to the multiscalar conditions and consequences of the extraction, production, distribution, and consumption of biomaterials. This includes close ethnographic observations of the sociocultural and ecological relations among different actors, including humans and more-than-humans.

This dissertation therefore contributes to literatures on bioeconomies in two ways: it is both based on case studies and grounded in a particular analytic. First, STS scholarship has largely discussed bioeconomies with reference to health sciences and technologies; the case of bioenergy economies has been marginal in these discussions. Literature that focuses on bioenergy economies tends to approach biofuels as a resource, not, what I attempt to show here, as a relationship-in-the-making (e.g., Birch, 2016; Birch & Calvert, 2015). My aim is to push past simplistic assumptions of the nature of bioenergy as resources for human consumption. Instead, I direct attention to the very discourses, practices, and processes through which photosynthetic organisms are potentiated into biomass – that is, as the basic building blocks or "stuff" of energy. This is an approach that I develop in the second chapter.

Further, the literature on bioeconomies is mostly based on studies of "Western" countries, including the United States and the United Kingdom. There has yet to be sufficient analysis of bioeconomies taking shape in non-Western countries. Many studies take the U.S. bioeconomy as the model for analyses of bioeconomies in other countries. This tendency, which reinforces the U.S. as the model for other economies, builds on assumptions that the bioeconomy originated in the United States through a concurrent rise of biotechnology and neoliberalism (Cooper, 2008). Studies that have explored the question of bioeconomies in different contexts — for example, Sunder Rajan's (2006) work that discusses drug markets in India — suggest that other countries follow a hegemonic American bioeconomy model and, by doing so, structure their markets in the image of America (p. 285). I find that sort of comparative study of the bioeconomy in the US and what could be called "other-than-Western" countries only serves to further reinforce dichotomies of the West versus the Rest (Hall, 1992). Instead, I challenge this analytic in order to examine how this process reproduces itself and to also to challenge the singular story that forms of modernization are always imagined in America's image.

Although Turkish scientists directly follow developments in the U.S. algal biofuels research and investments, the ways in which they embrace algal biofuels demands deeper analysis. My research findings suggest that the rising interest in algal biofuels in Turkey raises questions about the particular historical and cultural conditions that have allowed Turkish scientists to engage with algal biofuels research. In a political economic environment where industrialists, venture capitalists, or governments do not support biofuels, it is important to ask why scientists believe in the "potential of algae." I take up this question in Chapter Four where I suggest that modernization, as a concept, can help us understand how the bioeconomy unfolds in Turkey. Lastly, this dissertation treats potentiality as an analytic to unpack differences in the making of bioeconomies while understanding the discourses around algae's potential as world-making processes. Stated differently, my goal is to challenge imaginaries of sustainability that promote algae's innate potential as an energy resource, while concurrently denaturalizing perceptions about the "inherent potential" of the West as the model for all other bioeconomies.

Potentiality

My review of the scientific literature on algal biofuels led me to several articles that promoted algae as "the hope" for the future of biofuels. In this literature, I also came across several texts that referred to the "potentiality" of algae as a biofuel. When I reviewed my notes, I was surprised to see how much my understanding of "potentiality" had shifted throughout the research and writing process. My earlier notes describe potentiality and its variations (e.g., potential) as bound up with a number of concepts, such as, rhetoric, speculation, expectation, possibility, and becoming.

I came to recognize that my earlier interpretations of these articles were mostly in line with efforts that seek to explore "anticipatory regimes," especially in the life sciences (Adams et al., 2009). Yet, the idea of potentiality begged for a different way of thinking when it came to developing my analysis. The theme of the dissertation shifted from "the potentiality of algae as biofuels" to the "potentiation of algae as biofuels." I arrived at the general conclusion that algae must get potentiated again and again to remain a viable source of energy. That is what I call the potentiality of algae. In other words, the potentiality of algae is an *effect* created through contested, dynamic, and laborious processes of potentiation.

I find that shifting attention from articulations of potentiality to the potentiation processes is analytically productive. This shift also prevents me falling into the trap of representative modes of analysis. For example, rather than assuming that algae have a "natural" or innate potential on the basis of its rapid proliferation, I am forced to pay attention to the discourses, practices, and experimental configurations that potentiate algae as a rapidly proliferating organism. This ethnographic study therefore examines a range of sites, practices, and sociomaterials. I pay attention to growth charts, laboratory techniques, and containers, to scientific theories, imaginaries and ideas to understand the making of algae's potential as a fast growing biofuel source.

The concept of potentiality has long been subject to philosophical inquiry and can be traced back to Aristotle's reflections over *dynamis* versus *energia.* More recent accounts, for example, by Giorgio Agamben and Gilles Deleuze, develop theories of potentiality by diverging from Aristotelian thinking. In this dissertation, I do not aim to provide an epistemological or ontological account of potentiality. Rather, this is an *ethnography of potentiation*.[34] I look at "potentiality" inside of relations — notably, by exploring how scientists engage, embrace, and work with "algae's potential." I want to understand potentiality in-the-making – that is, as an effect of algae's potentiation in the hands of practitioners.

In the introduction of *Cultural Anthropology*'s special edition on "Potentiality and Humanness," Karen-Sue Taussig, Klaus Hoeyer, and Stefan Helmreich (2013) note: "[A]t the beginnings of the twenty-first century, potentiality serves as a central concept in the life sciences and in medical practices" (p. S3). The authors call for anthropologists of the life sciences to work

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[34] My use of ethnography of potentiation is not arbitrary. I differentiate it from the "anthropology of potentiality" (Taussig et al., 2013), or "sociology of potentiality" (Povinelli, 2011:15) or "approach[ing] potentiality empirically and ethnographically" (Weszkalnys, 2015: 617).

with the concept of potentiality "as analytic and as object of study" (Taussig et al., 2013: S5-S10). More, they open a new space to study potentiality alongside a history of anthropology. The threads looming in this space are worth noting as they introduce particular modes of attention.

The first thread delineates potentiality in terms of power and politics. *Potentia* means force, power, lord or possessor, and *potens* or *potence* connoting powerful, possible and capable. By noting the etymological roots of this concept, the authors argue, to "[frame] something in terms of potential is a political act" (Taussig et al., 2013: S6). The second thread approaches potentiality as an analytic. It refers to anthropological accounts underlying "emergence," that is the studies of societies and phenomena as dynamic and contested processes of becoming (ibid.). Further, the authors draw attention to conceptualizations of *potential* in contemporary anthropology in order to understand how "humans deal with that which is not in existence" (ibid.). This thread suggests that scholars focus on emergences as well as how humans cope with these emergences.

My ethnography of potentiation adds to the anthropological literature of potential by denaturalizing the idea of potentiality and, instead, illuminating how it is made. It does so by (1) working through how algae's potential is rendered as innate and self-evident; (2) documenting the material-semiotic-affective renderings of algae into energetic, labouring organisms and energy resources; (3) and, highlighting these renderings as potentiation processes in order to stress how naturalizations of "algae's potential" are in-the-making of sustainable bioenergy economies.

A Multi-Sited Ethnography of Potentiation

In 1995, anthropologist George E. Marcus proposed "multi-sited ethnography" against the conventional idea of ethnography—that requires long-term stay in a field of site. Multi-sited ethnography suggests that we must "follow people, connections, associations, and relationships across space (because they are substantially continuous but spatially non-contiguous)" (Falzon, 2009: 1-2). Here, research is envisioned through a series of juxtapositions in which global phenomenon is followed by moving through different places or concepts. Further, multi-sited ethnography means engagement with multiple scholarly literatures and disciplines, as it asks for fluency in many languages, technical and natural (K. Fortun, 2012). This approach aims to look at the same phenomenon from different angles at different scales. Such ethnography then provides dense and complicated accounts of how phenomenon under investigation works.

In this dissertation, I implement a multiscalar analysis of discourses, imaginaries, practices, materials, and affects around algal biofuels. I follow anthropologist Kim Fortun (2012) in my use of scale.[35] I employ an analysis of differing scales, which I consider as modes of attention. At the macro-level stands bioeconomies. At the micro-level, I examine experimental practices. At the level of materials, I look at devices used in experiments, most notably, test-tubes and infrastructures, such as integrated systems, and photobioreactors. At the meta-level stand dominant discourses such as potentiality, sustainability, modernity. I move back and fore in and between all these levels, which are not bounded entities, in each chapter, to bring them into a meta-level discussion. In anthropology, meta-level analysis, or meta-level thinking, refers to the study of dominant discourses. Analysis of dominant discourses allows anthropologists to "reveal

[35] Contrary to my previous training as a political science undergraduate and sociology Masters student, Fortun taught me that there is more to scholarship than micro, meso, and macro-levels of analysis. Previously, I had learned to see world only from specific perspectives, for example, through state-capital relations, and the relations between farmers and their organizations. I cultivated this different way of seeing the world through STS and alongside anthropologists, historians of science and technology, and feminist technoscience scholars. Notably, I began to understand the world through relationalities. This tuned me into how "things" bound up with each other, how they coproduce one another, as well as what continues and materializes anew in each moment of relating.

ways thought and language are organized to permit some articulations but not others" (Fortun, 2012: 76).

As Kim Fortun (2012) states, it takes time for a multi-sited ethnographer to ground the contours of phenomenon under investigation. In other words, it takes time for phenomena to become visible and meaningful to an ethnographer (p. 83). My own understanding of potentiality took almost four years to unfold. It was through an ethnographic mode of attention that I was able to make sense of the stories and practices around algae and biofuels. These ethnographic attunements helped me understand potentiality as a process through different materials, discourses, practices, affects, politics, and imaginaries. Further, the phenomenon itself pushed me to do multi-sited ethnography, while attending to different scales. This was by no means an easy process, I as had to physically and conceptually move back and forth between different fieldsites in different geopolitical contexts.

My ethnography is based both on fieldwork and critical textual analysis. The latter includes close readings of scientific articles on photosynthesis, algal, and algal biofuels research, among other related topics. It also comprises academic articles in the fields of STS, anthropology, geography, sociology, and political ecology as well as, legal documents, reports, memoirs, and newspaper articles, related both the US and the Turkish context. My fieldwork was mostly conducted inside of laboratories. Laboratory studies came to fore as a new approach to understand science and technology in the 1970s (Collins, 1985; Knorr Cetina, 1981; Latour & Woolgar, 1979; Lynch, 1985; Traweek, 1988). These studies provided a methodological way out from the trap of technological determinism. By investigating laboratory practices, STS scholars invite us to see how the technical nature of scientific knowledge is shaped by social and cultural practices. These initial laboratory studies examined how scientific facts are made, and how the work produced inside of laboratories comes to count as knowledge. Beyond these initial studies of scientific knowledge production, STS scholars' approach to laboratories has since changed and diversified. For example, some draw attention to questions of expertise, representations, politics, interventions, failures, and the materiality and affectivity of laboratory work (e.g., Hacking, 1983; Masco, 2006). Other scholars have discussed dimensions of institutional organization to further explore power-knowledge relations at national and global scales (e.g., Gusterson, 1998; MacKenzie, 1990). The boundaries, for example, between laboratories and fields, have also been subject to analysis (e.g., Kohler, 2002).

Aware of different approaches to laboratory studies, I initiated this project by stepping into a lab in order to learn about algae as a laboratory organism. I began this work at the Massachusetts Institute of Technology (MIT) as a visiting student in the anthropology program. This affiliation facilitated my access to MIT labs. In between October 2013 and May 2014, I conducted participant observation in world-renowned algal scientist Penny Chisholm's laboratory.[36] My ethnographic work in her lab included staging experiments, attending lab meetings, and listening life scientist Chisholm and her lab members talk about algae, photosynthesis, and ecology. Although I had participated in a number of online biology and ecology courses before starting out in the lab, everything was new to me. Once I learned how to grow and manipulate algae, I encountered the beings and doings of algae alongside an inquiry

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[36] In this dissertation, I have used pseudonyms for confidentiality purposes as well as to protect the identities of my interlocutors. In certain cases this was not possible. This limitation was either due to the public nature of the interlocutor's work (as is the case of Jonathan Trent), or to the nature of some of the laboratory cultures where I conducted fieldwork. In these close-knit lab communities, it would not be possible to guarantee anonymity of interlocutors whose identities would otherwise be recognized by their peers (e.g., Penny Chisholm, Halil Kavaklı). I have distinguished between these two styles by using (1) only first name introductions for anonymized interlocutors and (2) full names for interlocutors who gave me permission to use their real names, or whose accounts are drawn from public sources.

into researchers' work. For example, I learned about how researchers intervene into algal reproduction processes to obtain continuously growing algal cultures.

Conferences were also one of my main research sites.[37] During my stay in Cambridge, Massachusetts, I attended a number of conferences organized by the MIT Energy Initiative. I was not able to continue this research in the U.S. because of financial and time constraints. That said, I continued to follow past and current developments in the U.S. algal biofuels research and sector by conducting research at MIT's and Harvard University's library archives, and through online research. These included a material-semiotic analysis of documents, power point presentations, project proposals, reports, newspaper articles, and videos. My analysis of the U.S. based algal biofuels project, the Offshore Membrane Enclosure of Growing Algae (OMEGA project), in Chapter Three is based on online research.

I began my research in Turkey in the capital city of Ankara in October 2014, and over the course of a year, I did fieldwork in other cities including Izmir, Istanbul, and Bursa. I traveled back and forth between these sites as I visited laboratories, participated in conferences and interviewed algal and biofuels scientists. Between October 2014 and January 2015, I conducted my fieldwork studies in Demirer Lab at the Middle East Technical University (METU) in Ankara. I observed experimental processes involved in the design of integrated algal biofuels production systems coupled with wastewater and carbon dioxide treatment processes. I also interviewed lab members regarding their project and its funding through the Scientific and Technological Research Council of Turkey (TÜBİTAK). In Turkey, also I followed experimental studies of algal biofuels project in Kavaklı Lab at Koç University (Istanbul, Turkey) through interviewing biochemist Halil Kavaklı, listening to several of his conference presentation, and by

[37] My observations in the conferences have largely shaped my research in Turkey than the U.S. For their relevancy and importance for my research, see, Chapter Four.

conducting short-laboratory visits. Complimentary to these sites, I also visited another biologist's lab in a small university campus located in a coastal town in Southeastern Turkey. Finally, I also investigated an algal biofuels project, Istanbul Microalgae Biotechnologies Research and Development Center (IMBIYOTAB), through my participation in conferences. These experiences helped me to explore how algae get potentiated as biofuels feedstock through different designs, techniques, technologies, and knowledges.

In total, I conducted fifty-five in-depth interviews with scientists, activists, and industrialists; participated in ten conferences and symposiums in the energy sector, renewable energy infrastructures, biofuels, and algae; conducted fieldwork during visits to institutions including TÜBİTAK's Marmara Research Center, the Turkey Technology Development Foundation, the Ministry of Energy and Natural Resources, the General Directorate of Renewable Energy, and the Energy Market Regulatory Authority.

In the span of two years, I collected more stories that can be shared in this dissertation. What follows are the most significant stories that converge around the question of how algal biofuels, researchers, bioeconomies, sustainability, and modernity are potentiated together.

Outline

This dissertation examines the potentiation of algae within bioenergy economies. It begins with the experimental lives of algae in laboratories, moves to biofuels production systems, and concludes with an exploration of algal biofuels research in Turkey. In Chapter Two, I begin with an inquiry of how researchers in the life sciences stage algae's photosynthetic potential as the economic potential of these organisms. I center this examination on the juxtaposition of research undertaken in Chisholm's U.S. laboratory and Kavaklı's laboratory in Turkey. In the process, I examine how researchers' narratives and practices potentiate algal photosynthesis within larger bioenergy economies. I draw attention to the link established between algae's activities in the generation and maintenance of life on the earth and their potential to contributing to the making of bioeconomies. My aim in this chapter is to explore how algae's photosynthetic potential is staged materially and semiotically as its economic potential, both through the evolutionary stories scientists tell, and through the experiments they run in their laboratories. The subsequent chapter deepens this line of inquiry by expanding the analysis to look at biofuel production systems. It is from this vantage point that I can attend the ways that algae are potentiated as biomass for large-scale bioenergy markets.

Chapter Three draws on the juxtaposition of two different integrated algal biofuels projects, namely, Jonathan Trent's Offshore Membrane Enclosures for Growing Algae (OMEGA) project in the United States, and a Turkish algal biofuels project developed by an environmental engineer, Göksel Demirer, at Middle East Technical University (METU) in Turkey's capital, Ankara. The juxtaposition of these projects led by two scientists working in distinct geo-political locations allows me to examine different epistemic, affective, and temporal conditions of possibility for integrated algal biofuels projects. It documents the ways that algae get potentiated as sustainable energy resource. In so doing, this chapter explores how sustainability discourses shape the design of integrated systems of production, and how these systems make sustainability.

Chapter Four examines the political and economic vacuum in the Turkish biofuels sector. It studies how Turkish scientists embrace algal biofuels projects in a country where biofuels remain marginal not only to fossil fuel policies, but also other renewables, such wind and solar. It provides an ethnographic account of how Turkish scientists make biofuels matter in Turkey through a historical reading of the fraught relationship between Westernization and modernization processes in this country and through the stories of three algal biofuels scientists.

This dissertation overall aims to de-naturalize ideas about the U.S. as the dominant model for other bioeconomies, and simultaneously challenges the view of algae's potential as inherent and "natural." The next chapter begins by exploring how algae get potentiated in the hands of life scientists.

Chapter II: The Photosynthetic Potential of Algae in the Bioenergy Economy

> It is difficult to describe the thrill of studying *Prochlorococcus*. The name alone is enough to stop a conversation. Far from being tedious, studying this extraordinary little cell is like opening a present every day. It is a gift, and a responsibility. When people ask me about it I usually launch into my "photosynthesis appreciation" lecture trying to convince them that nearly all life on Earth comes from photosynthesis: making life from sunlight, air, and water. If I succeed at that, which is not easy, I go on to tell them that half of global photosynthesis is done by microscopic phytoplankton in the oceans, and that *Prochlorococcus* is the smallest and most abundant member of this "invisible forest." (Chisholm, 2011)

> Photosynthesis is indispensable. Life depends on photosynthesis. Algal cells use light and carbon dioxide, and make sugar, as you know. And sugar, glucose, constitutes the basis of all organisms from A to Z, except for viruses. No living being exists if there is no glucose. Autotrophs, the producers that have chlorophyll and photosynthetic capacity, produce sugar, and other organisms are fed by it. (Kavaklı, 2016)

In the first quote above, MIT scholar and biological oceanographer Sallie W. (Penny) Chisholm describes her passion for studying *Prochlorococcus*—the smallest and most abundant of all microalgae and cyanobacteria in the oceans. Her emphasis is on the photosynthetic potential of this little cell for making life on earth. In the second quote, Turkish biochemist Halil Kavaklı, of Koç University, Istanbul, echoes Chisholm's evaluation of the importance of photosynthesis to life. Yet, while Kavaklı assigns priority to the sugar produced by algae, Chisholm draws attention to algae's oxygen-producing role with the metaphor of an "invisible forest." In other words, while Kavaklı emphasizes algae's role as a producer of sugar, Chisholm underlines its ecological role in producing oxygen. In this chapter, I will investigate the stories life scientists tell, and document the experimental practices they undertake with algae as a photosynthetic organism. I will show how these stories and practices activate the photosynthetic potential of algae to render it more effective in theorizing ecological relations and simultaneously more productive as a commodity in the bioeconomy. This activation is what I call the *potentiation of algal photosynthesis*.

In both Chisholm and Kavaklı's stories, the photosynthetic potential of algae carries a deeper meaning: both see the fundamental importance of photosynthesis in sustaining life on earth, but also its importance as a potential force in the making of bioenergy economies. Focusing on photosynthesis—which makes life from sunlight, air, and water—Chisholm examines how photosynthetic cells and/or organisms obtain their energy. Kavaklı, instead, concentrates on glucose as the end product of photosynthesis, and draws attention to how non-photosynthetic life forms gain their energy from it. These approaches call up different meanings of *bioenergy*, and yet each refers to the photosynthetic potential of algae as sources of energy for a larger bioenergy economy. When I say bioenergy economy, I refer to a general usage of "economy" in the sense of the "management of the *oikos* [household]" (Graeber, 2012). Economy includes all discourses and practices that hinge on the "economic" management of life, whether it is in terms of efficiency, productivity or profitability—or, notably, of scale. For example, Chisholm refers to algae's productive management of the global oxygen-carbon cycle. She sees algae as part of a planetary-scale system. Kavaklı, by contrast, focuses on harnessing the productive power of algae inside of the cell itself. Kavaklı engineers algal cells to control their growth rates to make them profitable for a biofuels market. To query these differences, this chapter asks: *In what ways do researchers in the life sciences stage algae's photosynthetic potential as a form of economic potential?*

To stage algae's potential is a performative act. For example, when researchers stage algae as a provider of oxygen, matter, and energy, they do so by telling stories as well as by experimenting with photosynthesis. The way they talk about, and work with, algal photosynthesis potentiates some of these organisms' beings and doings, often to the exclusion of these organisms' other activities. In this chapter, I examine how researchers' narratives and experimental practices potentiate algal photosynthesis as productive resources for a future bioenergy economy. I draw attention to the link established between algae's potential in the maintenance of life on earth and the energetic potential of these organisms as resources. My claim is that algae's energetic potential is not innate. It takes work to potentiate algae as a viable resource for a bioeconomy. As life scientists naturalize algae's ecological role—for example, as an oxygen and energy provider—they concurrently potentiate algal photosynthesis as a productive contributor to bioenergy economies. I call this process *potentiation through naturalization.* By tuning into the work involved in naturalizing algae's energetic potential, this chapter challenges conventional understandings of "energy" as a natural resource and instead suggests that energy-as-resource is an effect of this process. These effects are themselves achieved through the *economization* of algae's lively bodies as energetic.

This chapter draws on the work of two algae researchers, Penny Chisholm and Halil Kavaklı. Chisholm has devoted her academic career to understanding a particular microorganism, *Prochlorococcus*, which she discovered with her colleagues during oceanographic explorations in the North Atlantic and the Pacific in the 1980s (Chisholm et al., 1988). In the Chisholm Lab, *Prochlorococcus*—the smallest and most abundant type of photosynthetic cyanobacteria (blue-green algae)—are domesticated as a model system for cross-scale systems biology studies of microbial and oceanic ecologies. Halil Kavaklı's research interests include molecular biotechnology and the circadian clock. *Chlorella vulgari*s, a species of algae, are the primary focus of his biofuels research. Kavaklı's research team mutates algal strains in order to design an economically feasible cultivation of algal biomass.[38] I base my

[38] This algal biofuels project was launched together with the establishment of the Energy Center at Koç University in 2012, supported by TÜPRAŞ, Turkey's only oil refining company. Its research areas include, fossil fuels, biofuels, and solar fuels.

analysis on participant-observation conducted in Chisholm's lab, as well as through a close reading of her publications. Interviews conducted with Kavaklı, as well as fieldnotes taken during several of his conference presentations, constitute the primary research for my analysis of Kavaklı's lab. This chapter also relies on secondary sources and scientific texts on photosynthesis, algae and algal biofuels.

Between October 2013 and May 2014, I spent eight months conducting participant observation in the Chisholm Lab. This included staging experiments, attending lab meetings, and listening to Chisholm and other lab members talk about photosynthetic organisms and their diverse roles in different ecologies. The more time I spent among the lab's members, the more I realized how scientists' narratives and experimental practices were not a mere amplification of Chisholm's story of photosynthesis—a story that made photosynthesis essential to the maintenance of life on earth. Rather, the stories and practices of photosynthesis that take shape in the labs potentiate algae as a labouring organism with different functions at different ecological scales. Further, during my time in the Chisholm Lab, I was specifically drawn to stories told about the evolution of life. In particular, lab members talked about algae differently than they would about other photosynthetic plants that are also utilized as biofuel feedstock—e.g., such as corn or sugar beet. For example, they spoke in terms of the evolutionary role that algae played in the accumulation of oxygen in the atmosphere. Thus, I recognized how "evolution" is a powerful "obligatory passage point" in the potentiation of algal photosynthesis (Callon, 1986).

In the Chisholm Lab, "evolution" is treated both as an analytic and as an object of study in understanding the ecological functions of cyanobacteria. For example, Penny Chisholm talks about the fundamental importance of cyanobacteria as photosynthetic organisms by referring to the role they played in the origins of life on earth. She and her lab members stage experiments to study the evolution of certain strains of cyanobacteria with different properties, including those that are able to live under low-light or high-light conditions. When I examine how researchers narrate and study the evolution of cyanobacteria or photosynthesis, I see that the evolutionary stories they tell are not neutral; rather, they enact particular forms of life, to the exclusion of others. To address these enactments, I will divide this chapter into two sections.

In the first sub-section on "oxygen," I focus on the mechanistic forms that oceanic life takes to ask: how and what kinds of evolutionary stories do scientists tell while talking about algae's photosynthetic potential? How do these evolutionary stories contribute to the potentiation of algal photosynthesis? I draw on Chisholm's talk of algae as "metabolic engineers," photosynthesis as "technology," and oceans as "machines," to demonstrate how her uses of mechanistic metaphors functionalize algae's photosynthetic role—for example, as an oxygen provider in the making and maintaining of microbial-oceanic ecologies. I also recognized that when researchers like Chisholm give algae particular roles in their evolutionary stories, algae are characterized not only as energetic and lively, but also as "ancient" beings. Chisholm has referred to algae as "ancient metabolic engineers"—at once figuring algae as primordial and as an active, readily available energy resource. Chisholm sees deep oceans as fossil fuel reserves that are composed of "organic carbon in the form of aggregates, dead [algal] cells"—what anthropologist Natasha Myers (2016a) might call "once-living matter." Broadly, this section will examine how researchers functionalize algae's ecological role through evolutionary stories that render algae as both labouring organisms and as an accumulative, aggregate energy resource. This is what I call *economization through functionalization.*

Further, in the second sub-section on "light," I examine Chisholm's employment of *Prochlorococcus* as a model system. Chisholm positions *Prochlorococcus* in a distinct evolutionary narrative, namely, one that draws on the theory of "symbiogenesis" in order to emphasize interspecies affinities. I show how her rendering of *Prochlorococcus* as a model for understanding biocomplexity also *instrumentalizes* these organisms on the basis of their abundance and simplicity. Instrumentalization is not a neutral act; rather, it domesticates organisms as use values for humans through laboratory practices. I call this work *economization through instrumentalization.* I conclude this first section by showing that Chisholm's passion for algal photosynthesis is not merely an appreciation of algae's role in the maintenance of life, or its role in managing a rapidly changing climate. Nor is her passion for algae just driven by anxieties about the future. Rather, her desire to know more about oceanic algal life is the consequence of multiple "interventions" that instrumentalize, functionalize, naturalize, economize, and, in the process, potentiate algae's ecological beings and doings. While researchers produce knowledge through these interventions, they also render algae as both a form of "living labour" and as once-living aggregates of energy that could be called "dead labour." Later, I will show how differences between "living labour" and "dead labour" become blurred in algal biofuels research.

By attending to the experimental lives of algae, the second half of this chapter details how researchers economize algae's photosynthetic potential. I base my findings on participant observation that I conducted across two fieldsites; the first involves an experiment designed by one of Chisholm's PhD students, and second, the algal biofuels experiments conducted in Kavaklı's lab. I show how experimental interventions potentiate algal photosynthesis as an efficient and productive process for generating potential economic value. I draw attention to experiments in which researchers aim to grow algae in containers inside of enclosed artificial environments, such as test tubes. By turning to the techniques and technologies that researchers use to grow algae, I examine how researchers optimize growth conditions and manipulate algal cells. I claim that such experimental interventions into the reproductive potential of algae aim to push algae both beyond known "limits to growth" and also beyond known "limits to efficiency." In this regard, algae's photosynthetic potential materializes as a matter of concern among researchers who want to generate biomass from fast-growing organisms like algae. By the end of this chapter, I will demonstrate how some researchers are attempting to bypass the limits of "natural" algal growth by growing these organisms in the dark.

The juxtaposition of the research conducted in Chisholm's and Kavaklı's labs can also be illuminating in other ways. Comparing these laboratory cultures highlights key differences in the ways in which life science researchers economize algal reproduction for productive ecologies and biofuels markets. These differences matter in understanding the different ways that researchers imagine algae's photosynthetic potential. In these stories, we learn that algae are energetic bodies. They form "invisible forests" in oceanic ecologies at the same time that they provide materials like glucose—elements that can be used in the reproduction and growth of other non-photosynthetic energetic bodies. Further, other materials produced by algae—lipids, for example—become resources for producing and utilizing energy in the form of automotive biofuels. Thus, algae do more than just obtain their energy through photosynthesis, they are seen as energetic bodies that labour and accumulate potential value for economic markets.

This chapter illuminates how algal photosynthesis and algae researchers participate in world-making practices. Together, algae and people are, I argue, remaking relations between humans and more-than-human forms of life, between life and death, as well as between ecology and economy. These world-making practices are charged with anxieties and passions in such a way that they reconfigure the moral economies that naturalize algae's photosynthetic potential as an economically valuable commodity for sustainable ecologies. In this regard, my investigation into how researchers potentiate and, therefore, economize algal photosynthesis speaks to the dynamics between the life sciences and capitalism. This chapter will thus contribute to discussions in the STS literature on bioeconomies and the economization of life (e.g., Cooper, 2008; Helmreich, 2009; Murphy, 2017; Sunder Rajan, 2006; Waldby & Mitchell, 2006).

STS scholars have developed a distinct analytics and objects of analysis to examine the relation between economy and the life sciences. Melinda Cooper's (2008) analysis of the bioeconomy as practice at the scale of epistemologies helps me to see how evolutionary theories that emphasize the complexity of biological growth are linked to theories of complex economic growth. Cooper draws attention to particular evolutionary theories that relocate "the driving force of evolution in the world of microbes" (Cooper, 2008: 35). These evolutionary theories provide an understanding of evolution at the scale of the biosphere. More, they redefine photosynthetic microbial lives in relation to their "ability to transform solar radiation into new chemical compounds, thus accumulating a relentless surplus of 'free energy' over and above the chemical deposits already available on earth" (ibid.). The narrative of a "surplus of free energy" is linked to the idea of biological productivity, which in turn constitutes the conditions for the extraction of surplus value in the realm of economy. This line of thinking, according to Cooper, promotes an imaginary that transcends the "limits to growth" and goes beyond Malthusian understandings of life. She demonstrates that the idea of limitless growth is coupled to the promise of a "surplus of life," making visible the extension of the speculative logics of financial capital into the sphere of life sciences. Cooper's insights help me critique the evolutionary narratives of algae's photosynthetic potential.

I also draw on the works of Kaushik Sunder Rajan (2006), Catherine Waldby and Robert Mitchell (2006), and Stefan Helmreich (2009) to understand how biomaterials are economized in the life sciences. Sunder Rajan's (2006) comparative study of biocapital in the US and Indian genomic research and drug development markets provides a generative analytic. Sunder Rajan helps me think about algae's economic value by focusing my attention on systems of valuation. He approaches value both in the sense of the ways materials acquire value on the market, and of the production of biocapitalist value as a discursive act—for example, through advertising or the selling of futures. The systems of valuation at stake in this chapter include both the economic value algae acquire through the stories and experimental practices taking shape among researchers.

Further, I look to Catherine Waldby and Robert Mitchell's *Tissue Economies* (2006), which draws attention to the fragmented character of biomaterials. Walby and Mitchell discuss the ways that the disembodied, or alienable, nature of biomaterials plays a role in systems of valuation. Their analysis helps make visible the valuation of algae on the materials extracted from algae as biovalue—such as algal lipids and other compounds. These studies of systems of valuation offer an important contribution to the literature. However, they alone are not sufficient for understanding the role of experimental practices in the creation of economic value from biomaterials. Drawing attention to the experimental lives of algae, I want to investigate how researchers domesticate, functionalize, and instrumentalize algal photosynthesis, which in turn economizes algae as labouring organisms and energy resources.[39]

Stefan Helmreich's (2009) discussion of the instrumentalization of biomaterials through laboratory practices constitutes the main point of departure for this chapter. Helmreich helps me analyze how scientists' staging of experiments links algae's photosynthetic potential to its economic potential. By following Marx's well-known formula M-C-M', "where M stands for

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[39] This chapter does not approach to the question of "labour" as an object of study. For an analysis of labour in bioeconomies, see Cooper & Waldby, 2014.

money, C for commodity, ‘ for the surplus value gained in a profitable exchange of a commodity for money, and M’ for the total capital produced by that exchange,” Helmreich writes an analogous formula: B-C-B’ (Helmreich, 2009: 125). In this scenario, “B stands for biomaterial, C for its fashioning into a commodity through laboratory and legal instruments, and B’ for the biotech product (or, perhaps, biocapital) produced at the end of this process, with ’ the value added through the instrumentalization of the initial biomaterial” (ibid.). Helmreich underlines how economic value is already anticipated as innate within biomaterials before they are subject to laboratory experiments and legal practices—and before they come to circulate in markets. This chapter adds to Helmreich’s investigation by elaborating on the ways researchers economize algal photosynthesis to render algae not only into energetic labouring organism, but also as an accumulated energy resource.

In her recent book, *The Economization of Life,* historian Michelle Murphy (2017) explores the history of population and economy as two “aggregate forms of life.” Murphy helps me to see how economy becomes our living environment at the same time as it is coupled with a naturalized population growth curve, one that is abstracted into a universalizing image of the balance between life and death. From bacteria growing on a petri dish, to *Drosophila* multiplying in a bottle, to humans reproducing in a class, city, nation, or on a planet, or to cyanobacteria in test tubes, Murphy demonstrates how life everywhere gets “contained” (p. 4). She studies economization as a “historically specific regime of valuation,” one that governs life on the basis of its ability to advance the macroeconomy of the nation state. This is a regime of valuation that is historically specific and takes shape in and through technoscientific practices and social science methods rather than in markets (p. 9). Although Murphy’s analytical scale is different from the one employed in this chapter, I also stress how economic value is generated through the optimization of what she calls "surplus aggregate life." She differentiates this mode of economic value creation from the forms of valuation generated through labour. Her analysis thus differs from the works discussed above that focus on biocapital and/or biovalue. Murphy's analysis helps me to interpret experimental interventions that seek to optimize algae as "aggregate life."

This chapter builds on these insights on the economization of life to demonstrate how researchers potentiate algae as both labouring organisms and forms of aggregate life. It is the lens of the energetic—a phenomenon characterized by energy—that helps me discern links established between labouring and accumulating. I explore how laboratory experiments that investigate the energetics of algal materials are concurrently *making matter energetic*. I focus on the "material-semiotics" of algal research, looking closely at how biomaterials are "rendered" energetic (Haraway, 1994; Myers, 2015). This chapter therefore examines how algae are economized through metaphors and laboratory instruments that render their bodies and materials in the form of energetic labourers. My claim is that these ways of rendering algae are key sites for documenting the relationship between capitalism and research in the life sciences. I intend to make visible how the "functions of algae" (e.g. how algae absorb carbon dioxide) and the "products of algae" (e.g. biofuels) are linked inside algae-based bioeconomies.

Alongside the economization of energetic bodies, this chapter also explores the STS literature on biofuels (e.g., Birch, 2016; Birch & Calvert, 2015). In their article "Rethinking 'Drop-in' Biofuels: On the Political Materialities of Bioenergy," Kean Birch and Kirby Calvert (2015) develop an analysis of biofuels that takes into account the political materialities of bioenergy. Their project is in line with Timothy Mitchell's (2011) discussion of the material politics of energy in *Carbon Democracy.* Birch and Calvert differentiate the political materiality of biofuels from the materiality of the fossil fuels that Mitchell's book describes. To the authors, the first crucial contrast between fossil fuels—what Mitchell calls "buried sunlight"—and biofuels, is that bioenergy is "grown sunshine" (Birch & Calvert, 2015: 61). This line of thinking, however, does not problematize the promotion of biofuel as "grown sunshine." This metaphor of "grown sunshine" actually re-enacts growth-based imaginations of biomaterials, and thus re-naturalizes the photosynthetic potential of algae as economically valuable. Such metaphors reproduce a hegemonic approach to photosynthetic materials as the stuff of bioeconomies in the form of biomass, or, in Murphy's words, aggregate life. This chapter intends to make this hegemonic approach strange by troubling the naturalization of algae as resource.

In this chapter, I push past easy assumptions about the nature of bioenergy as a sustainable energy resource for human consumption, and direct attention towards the ways that photosynthetic organisms are rendered as mere biomass—the stuff of energy economies. The following chapter will deepen this line of inquiry by offering an analysis of biofuel production systems. It is from this vantage point that I will examine how algae are potentiated as biomass for large-scale bioenergy markets.

Algae as Labouring Organisms in Evolutionary Stories

Algal scientist Russell L. Chapman[40] is known for his "unusual approach to presenting the history and importance of algae" (Schwartz, 2010). Chapman's focus is on the primacy of algae: "He drives home the fact that, for example, without algae we wouldn't have lives in the first place. Nor would we have plants, nor oxygen in our atmosphere." When I read Chapman's (2013) evolutionary story of algae in his article, "Algae: The World's Most Important 'Plants'," I learned how he envisions algae's role in "our lives" as energy providers for human consumption:

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[40] The former executive director of the Center for Marine Biodiversity and Conservation at the Scripps Institute of Oceanography, University of California, San Diego.

> Early in the history of life, algae changed the planet's atmosphere by producing oxygen, thus paving the way for the evolution of eukaryotic organisms. In an era in which the consumption of fossil fuels is a prime topic of concern, few people realize that the oil we currently exploit comes mostly from Cretaceous deposits of marine algae. Moving from ancient times to the present, the algae remain more important than most people realize…As we use up the oil deposits provided by the ancient algae, we are turning to the modern algae for help. Given the photosynthetic abilities of the algae, they are one of the major focuses for sustainable biofuel production and CO_2 consumption (Chapman, 2013: 12) .

Chapman's suggestion that algae are "the world's most important plants" is not a simple taxonomic reduction of algae to plant life. He establishes a link between algae and plants on the basis of their *photosynthetic potential*, and differentiates algae's evolutionary story. In this story, algae not only paved the way for the evolution of eukaryotic organisms—fungi, plants, and animals—but also offered abundant energy resources for humans. Chapman underlines how, from ancient to modern times, "our lives [have] depend[ed] on algae": "Roses are pretty and oak trees are impressive, but no other groups of 'plants' have done so much, for so long, and, for so many as have the algae!" (Chapman, 2013: 5). In the first half of the chapter, I examine how researchers hail evolutionary stories of algae while speaking about algae's photosynthetic potential. I note how these evolutionary stories render algae as energetic resources for productive ecologies and economies.

The way that Chapman renders algae can be taken as an example of the evolutionary stories that proliferate in algal biofuels research. These tales reduce algae's photosynthetic potential to the functional labour of making of oxygen, matter, and energy. Just as ancient algae, or "dead algae," constitute fossil fuels, "modern algae," or "living algae," can now produce biofuels.[41] In other words, just as algae's "dead labour" serves fossil-fuel-based economies, their "living labour" can now drive bioenergy economies. Algae are important because they have been labouring continuously for energy economies. I ask: how do evolutionary stories of algal photosynthesis potentiate algae as resources for bioenergy economies?

STS scholars have explored how evolutionary thinking in the life sciences is shaped by economic logics. By focusing on the field of chemical ecology, anthropologist Natasha Myers and historian Carla Hustak (2012) have explored how neo-Darwinian understandings of plants fetishize economic logics in line with functionalist accounts of adaptation. Sociologist Melinda Cooper (2008) has analyzed how complexity theories in evolution studies, such as the endosymbiosis theory that identifies microbes as the prime movers of evolution, are linked to theories of complex economic growth. Historian Sharon E. Kingsland (2010) has traced the disciplinary exchanges between ecologists and economists, and provided an analytic for examining how economic logics are inherent to evolutionary stories in these disciplinary interchanges. Kingsland's investigation the traffic between the fields of ecology and economy constitutes a key stepping-stone for my analysis here.

Kingsland examined the work of American mathematician Alfred J. Lotka (1880-1945), who developed the idea of "economy of nature" by transferring mathematical methods from economics to ecology (Kingsland, 2010). According to Kingsland, Lotka's efforts "harkened back to the earlier bioeconomic analogies," which were employed in the conceptions of evolution. For example, Herbert Spencer (1820-1903) suggested that evolutionary progress is an

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[41] What Chapman refers to here by interpellating algae as "modern" is "living algae" that can be cultivated, extracted and served for human consumption. This particular reading of modernity infers the hegemony of science and human control over nature, in a more towards progress. It is important to see how Chapman's evolutionary demarcation between "ancient" and "modern" algae claims a disengagement from the history of fossil fuels with the "newness" of algae as biofuels. Chapter Four will explore questions of modernity and/or what it is to "be modern" in more detail.

economic problem; it depended on how to balance the costs of maintenance and reproduction of life (ibid: 232, 235). German chemist Friedrich Wilhelm Ostwald's (1853-1932) comparison of the evolution of machinery to organic evolution also echoed in Lotka's "economy of nature" that figures the world as a "giant engine." Lotka had revisited Darwin's natural selection from the perspective of energy flows and specified that organisms compete to capture available energy. Lotka, well-known for his role in the development of population ecology, promoted the analytic of energetics—the doctrine of energy—to study evolution. Kingland's reading of Lotka suggests that the logic of economy was already enlisted into evolutionary theories through the lens of "energetics."

Lotka's "economy of nature" has influenced a number of fields of study—including, for example, ecological economics—that focus on energy and matter flows in ecologies. Ecological economists suggest that limitless growth is impossible on a finite earth that is perceived to be a closed system.[42] For example, one of the leading figures of ecological economics, Nicholas Georgescu-Roegen (1976), has claimed that economic growth is limited by the availability of energy on earth. For ecological economics, "the economic system is a component of ecological system rather than environmental inputs and outputs being components of the economic system" (Beder, 2011: 146). This field of study is critical to environmental economics, which adopts the neoclassical economic idea of "scarcity of natural resources" (ibid: 140).[43] Although ecological

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[42] The history of ecological economics goes back to the late 1980s, to the establishment of the International Society for Ecological Economics in 1987. Although the scholars contributing to this field of study were basically economists—namely, Herman Daly and Joan Martinez-Alier, together with zoologist Ann-Mari Jansson and one of her students, Robert Costanza—the aim was to bring economists and ecologists together (Beder, 2011: 146). For a detailed discussion of the early history of ecological economics, see Røpke, 2004.

[43] For further discussion of the difference between ecological economics and environmental economics, see Beder, 2011. On environmental economics, see also Folmer, 2002; Pearce, 2002; Spash, 1999; Thampapillai & Sinden, 2013.

economists argue against market solutions to environmental problems as advocated by environmental economists, they still reduce the study of ecologies to the analytic of energetics.

Furthermore, Lotka's ideas also had an impact on ecosystem ecology, which quantitatively studies the flows of energy and matter. This field provokes the imagination of ecologies as ecosystems, large cycling entities. These imaginations render the components of ecologies into energetic materials, where energetic flows circulate in and through different ecosystems. These renderings are not mere performances, but are also performative; they economize ecologies, both materially and semiotically (Haraway, 1991; see also Myers, 2015). As Lotka's "economy of nature" traverses different fields of study, it not only reproduces visions of life in economic terms, but also promotes understandings of ecology as a closed system through which energy and matter flow. It is this vision that permeates Penny Chisholm's evolutionary story of algae's photosynthetic potential.

By focusing on Chisholm's "photosynthesis appreciation" talks, the following section addresses how these evolutionary stories of photosynthesis, algae, and life come to lay the groundwork for the potentiation and economization of algal photosynthesis. I draw attention to how Chisholm functionalizes and instrumentalizes algal photosynthesis through mechanistic metaphors and systems thinking. This section, therefore, aims to make algae visible as *labouring organisms* and as aggregate forms of *accumulated life*.

Oxygen

In 1970, John M. Olson, an expert on photosynthesis, published, "The Evolution of Photosynthesis," in *Science* magazine. Under the title reads the caption, "Hypothesis: Photosynthetic bacteria and blue-green algae shared a common photoheterotrophic ancestor"

(Olson, 1970).[44] Three decades later, Olson revisited his work in an article for *Photosynthesis Research* (2001). In this piece, Olson re-examines his earlier hypothesis suggesting that the origin of life on earth is "intimately" connected with the evolution of photosynthesis. Olson replaced his earlier hypothesis with the proposition that "photosynthesis may be invented by the Bacteria after their divergence from the Archea [*sic*]" (ibid: 95).[45] His latest hypothesis is now generally accepted in photosynthesis research. These tales of the origins of life and the evolution of photosynthesis are also stories about algae. The more I attended to these evolutionary stories, the more I realize that they play a significant role in the potentiation of algae for productive ecologies.

Stories craft worlds. I draw on a graph produced by Anthony W.D. Larkum (2013), a pioneer in photosynthesis, algae, and algal biofuels research, to illustrate this point. In the graph below, Larkum places "evolutionary milestones" in relation to the changing concentration of oxygen in the atmosphere. Here, Larkum shows us the ozone layer, the process of oxygenic photosynthesis, the event of the Cambrian explosion, the organelles mitochondria, and specific life forms—namely, photosynthetic bacteria, cyanobacteria, and eukaryotes (algae and land plants). In short, these "milestones" appear as signposts of life's evolution in relation to oxygen accumulation in the atmosphere.

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[44] Photoheterotrophs are organisms that use light for energy, but must obtain carbon in organic form.

[45] The Archaea is the domain of single-celled microorganisms. Archaeans are different from Bacteria and Eukaryotes in many ways. For example, archaeal lipids lack the fatty acids.

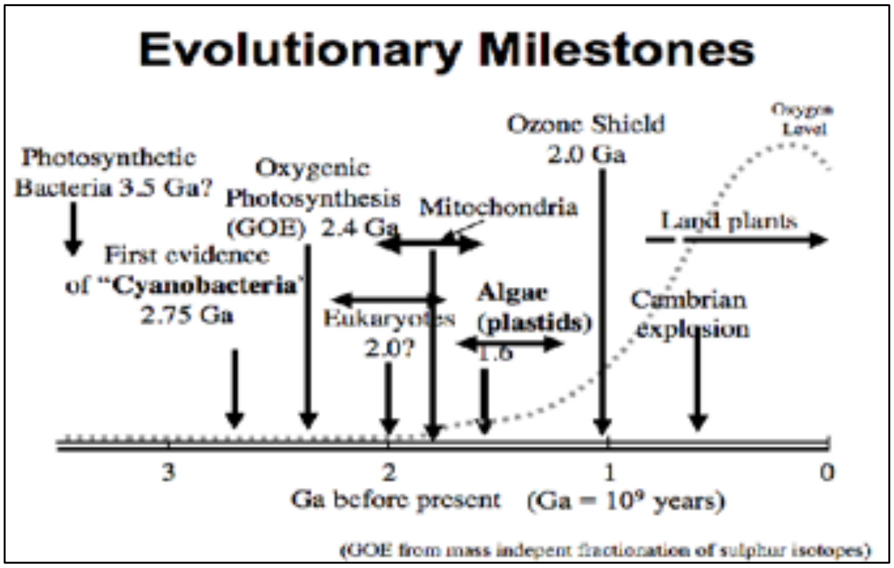

Figure 1 The Evolution of Photosynthesis
Screenshot from Larkum's (2013) "The Golden Apples of the Sun: the History of Photosynthesis-so far." Larkum uses this graph to explain the "Evolutionary Milestones of Earth History and Photosynthesis."[46]

Yet the graph does not contain the whole story. Larkum, instead, adds to the image of evolution by explaining life before photosynthesis by writing:

> The Earth was formed about 4.5 billion years ago (GA) at the beginning of the Solar System as the planets consolidated out of clouds of dust… Approximately 3.8 billion years ago (GA) life spread over the world. Prior to this time it is considered that the surface of the Earth was too hot and unstable to sustain the widespread occurrence of living cells, except in local pockets. There has been much discussion as to how life started and what form of nucleic acid formed the first replicating structures. It has recently been suggested that an early development was the evolution of organic compounds that would shield organisms from UV radiation and this led to the earliest processes of photosynthesis (Larkum, 2013: 834-835) .

According to Olson and Larkum, life on earth began prior to photosynthesis. Anoxygenic photosynthesis preceded photosynthesis as we know it today (oxygenic photosynthesis).[47] Although anoxygenic photosynthesis has its part in Larkum's story of evolution, what Penny

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[46] "[T]he scale for oxygen level is relative: the present concentration of oxygen in the atmosphere is 21%." (Larkum, 2013: 835).

[47] When German botanist Theodor Wilhelm Engelmann (1843-1909) reported the results of his experiments with purple sulfur bacteria at the end of the nineteenth century, there was doubt whether these bacteria were photosynthetic at all because they were not producing oxygen. Later, Hans Molisch's experiments (1856-1937) suggested that these bacteria were indeed photosynthetic. Purple sulfur bacteria are different from cyanobacteria, algae, and plants: they do not use water as their reducing agent, but rather hydrogen sulfide (Gest, 1991).

Chisholm terms “life-as-we-know-it,” began with oxygenic photosynthesis. According to Chisholm, it is in *this* life that photosynthesis is indispensable:

> The most ubiquitous, important, and profound dimension of life on Earth is the process of photosynthesis. Had some ancient marine microorganism not acquired a key mutation some 3.5 billion years ago, allowing it to split water instead of hydrogen sulfide, the evolution of life on Earth would have taken an entirely different trajectory. Photosynthesis was the ultimate “disruptive technology” of its day—converting carbon dioxide gas into organic carbon molecules using solar energy and splitting water-releasing oxygen gas. Over billions of years oxygen transformed the very nature of our planet, making it possible for more complex forms of life to evolve and spread across the Earth (Chisholm, 2014: 7) .

In Chisholm’s words, photosynthesis was a “disruptive technology”:[48] According to her, if photosynthetic bacteria had not acquired a key mutation—the ability to split water instead of hydrogen sulfide—the trajectory of life on earth would have been entirely different. Oxygen levels in the atmosphere would not have increased, and complex life forms—such as plants, animals, and humans—would not have evolved. Chisholm has devoted her career to a genus of cyanobacteria, *Prochlorococcus*—what she calls “the modern-day descendants of the ancient metabolic engineers that oxidized our planet” (Chisholm, 2014: 7). As photosynthesis becomes a technology in Chisholm’s story of oxygen accumulation in the atmosphere, cyanobacteria also become potent “metabolic engineers.” Chisholm’s story suggests that ancient cyanobacteria engineered life through photosynthetic technologies. For Chisholm, cyanobacteria continue to engineer “modern” oceanic ecologies:

> We can think of the ocean ecosystem as a photosynthetic machine in a sense. A critical function of this machine is to steadily pump carbon dioxide from the atmosphere into the surface oceans and then export it to the deep ocean, and at the high pressures and cold temperatures of the deep ocean, that carbon dioxide is what’s called sequestered for hundreds of thousands of years. The deep ocean represents a very large reservoir of CO2 and that’s an important part of the global

[48] Chisholm’s reference to “disruptive technology” is separate from the term popularized by the Harvard Business school professor Clayton M. Christensen (1997) to signify the technology that replaces the established one towards industrial innovation under a neoliberal regime. In Chisholm’s evolutionary depictions, photosynthesis is figured as “disruptive” in the sense that it unsettled life on earth by creating other ways of living and being for more complex life forms, including humans. Yet, photosynthesis did not make atmospheric changes by itself; rather, these changes were made possible in tandem with cyanobacteria.

> carbon cycle. The phytoplankton are at the heart of this pump; what they do is the CO2 in from the atmosphere into this complex food web where much of it is recycled and comes right back out again, but some of it stays as organic carbon in the form of aggregates, dead cells, fecal pellets from zooplankton (Chisholm, n.d.) .

Chisholm swaps the story of oxygen accumulation in the atmosphere with a concern over global carbon cycles. She describes the ocean ecosystem as a "photosynthetic machine." Inside this machine, cyanobacteria, and marine algae labour to pump carbon dioxide into the ocean from the atmosphere. Chisholm's use of mechanical analogies to explain the role of oceans and photosynthetic organisms further reproduces the power of machine metaphors—metaphors which have long been subject to critiques in STS literature (e.g., Haraway, 2006; Keller, 2000, 2003; Myers, 2015). STS scholars have argued that such machine tropes are not neutral; the machine is a powerful metaphor in the life sciences, and shapes the imaginations of life in popular accounts. These metaphors are also political; they activate functionalist and instrumentalist forms of storytelling. They are machinic "renderings," as Myers argues in her study of protein crystallographers who model the chemical structures of lively molecules. According to Myers:

> Machinic renderings produce a range of effects and affects. Renderings tell stories: they activate modelers' imaginations and shape their perceptions; and at the same time, the models and meanings they mobilize can act recursively to sediment particular ways of seeing and storying life…[R]enderings transform how the stuff of life is made visible, tangible, imaginable, and workable (Myers, 2015: 161-163) .

Spurred on by Myers's analysis, I claim that Chisholm's framings of cyanobacteria as "metabolic engineers," photosynthesis as "technology," and oceans as "photosynthetic machines," make visible the beings and doings of photosynthetic organisms in microbial-oceanic ecologies in particular ways. One reading of Chisholm's framing is that cyanobacteria are themselves appendages of a larger oceanic-photosynthetic-machine. In this reading, cyanobacteria are hooked into a "giant machine" as "living labourers"—that is, they are organisms that labour to reproduce life on earth. Stated differently, as long as organisms are rendered as labourers they become "visible, tangible, imaginable, and workable" as valuable resources (Myers, 2015: 163). Machinic renderings thus not only functionalize photosynthetic organisms as elementary building blocks of productive ecologies, they also potentiate algae as labouring organisms inside of larger energy economies.

Yet, algae's productivity is not limited to their ecological role in global carbon-cycles. Algae reproduce, die, and sediment—they become food for other marine organisms and for bacteria undertaking anoxygenic photosynthesis. As Chisholm says, in "our hands," they can also become fuel:

> As that oxygen accumulated in the atmosphere, organic carbon buried and compressed-becoming fossil fuel and accumulating over billions of years. This is the "buried sunlight" humans began to exploit a few hundred years ago, changing profoundly our civilization and its relationship to the natural world (Chisholm, 2014: 7) .

For Chisholm, dead cyanobacteria and microalgae are fossil fuels, or what she terms "buried sunlight." This connection between fossil fuels and algae's "dead labour" illuminates one of the substantiated propositions in algal biofuels research: since the remnants of algae can form into fossil fuels over time, these organisms can be considered as energy sources in-the-making. In other words, these evolutionary narratives of "ancient algae" as "buried sunlight" figure algae as potential energy resources. Such stories naturalize algae's labour in energy production, and make them readily available for human use. I evaluate this extension of algae's ecological role as an energy provider alongside what I call its "energetic fallacy." I employ the term "energetic fallacy" to trouble reductionist imaginations of algae's beings and doings with regards to energy. Through the lens of this energetic fallacy, it is possible to see that evolutionary narratives establish a connection between "living algae" and "dead algae," and in so doing, envision algae as energetic, labouring bodies that simultaneously produce and accumulate energy.[49] These stories blur the differences between "dead labour" and "lively labour" in such a way that algae's functional role as an oxygen producer gets intertwined with their role as energy providers.

Yet, Chisholm also underlines how the exploitation of this "buried sunlight" changes humanity's relationship with the so-called "natural" world. For example, humans can and do intervene in the global carbon cycle by employing extraction technologies, including oil drilling technologies. Chisholm argues against such practices, as they disrupt the net carbon balance sustained through the ocean ecosystem. During one of our interviews, Chisholm also explained to me that when algal biofuels are burned, they are no different from fossil fuels in terms of net carbon balance. She drew an image of the earth as a closed system and of the oceans in it taking in carbon dioxide (Figure 2).

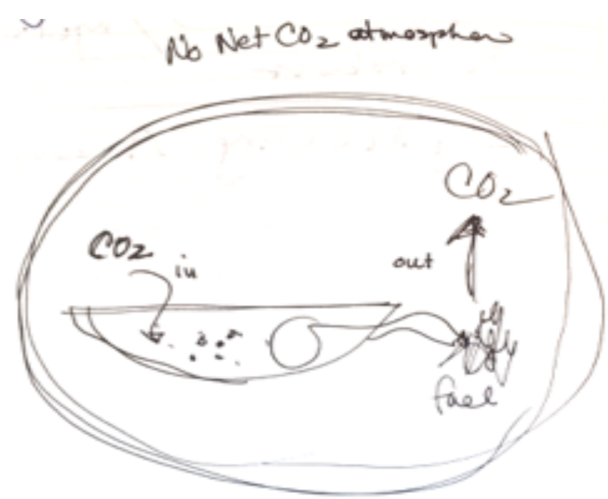

Figure 2 Carbon Dioxide Cycle
Photo of the Chisholm's drawing taken and edited by the author. Chisholm explains "Net Atmospheric Carbon Dioxide" and shows that when fossil fuels are burned, they release absorbed carbon dioxide by photosynthesis. It is also relevant for biofuels.

In her drawing of the net carbon balance, Chisholm imagines the earth as a closed system. Her reference to the carbon cycle in turn reproduces other cyclical models of life. It is a vision similar to the mechanistic ontologies of cybernetic systems, which puts emphasis on the role of

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[49] The analysis of the relation between "labouring" and "accumulating" at the scale of organisms needs further thinking, analytics, and research that go beyond the focus of this dissertation. Nevertheless, I began scrutinizing this relation by tracing evolutionary stories that link fossil fuels and biofuels.

"circuitry" (Fujimura, 2005). Through her drawing, she provides a mechanistic understanding of oceans, configuring their function as "photosynthetic machines" in a feed-back loop. Although Chisholm's critique of this exploitative logic challenges prevailing views, her evolutionary narratives do not resist the ongoing economization of life—an economization that is central to ecological and neo-Darwinian views. The cyclical models she draws reduce life to the flows of matter and energy; this, in turn economizes life, through the quantification, calculation, and measurement of matter and energy.

This section has showed that Chisholm's evolutionary stories about algae's ecological beings and doings are centered on machinic metaphors that functionalize algal photosynthesis as valuable resources in bioenergy economies. Beyond employing machinic metaphors, Chisholm also *instrumentalizes* algal photosynthesis in her studies of oceanic microbial lives by domesticating a particular strain of algae as a model system (Paxson & Helmreich, 2013). The next section discusses this practice of *economization through instrumentalization,* by drawing attention to the relationship between the evolutionary theory of symbiogenesis and the origins of photosynthesis as a concept.

Light

When eighteenth-century natural philosopher Joseph Priestley (1733-1804) conducted the first experiments on vegetal gas production—in his words, "dephlogisticated air"— he emphasized how gases mediate the interdependence of plant and animal life.[50] At that time, the requirement of light for photosynthesis was not known. By 1779, Dutch physician Jan Ingenhousz (1730-1799) recognized the essential role of light for photosynthesis and specified leaves as the primary

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[50] The acknowledgment that Priestley provided the initial understandings of gas produced by plants is contested. According to some, French chemist Antoine Lavoisier (1743-1794) was the one who first understood the nature of (oxygen) gas, which Priestley called as "dephlogisticated air." (e.g., see Beretta, 1995; Holmes, 1988).

sites of oxygen formation (ibid.). Like Priestley, Ingenhousz's notion emphasized interdependencies between animals and plants. Despite Ingenhousz's findings, the term "assimilation" was used as recently as the end of the nineteenth century to explain what we understand today as the process of photosynthesis.[51]

American botanist Charles Reid Barnes (1858-1910), by contrast, proposed two alternative concepts, "photosyntax" and "photosynthesis," in lieu of assimilation. With this proposition, light came to the fore in photosynthesis research, and the "physiological mechanisms" of plants and animals were differentiated.[52] In his 1893 paper, "On the Food of Green Plants," Barnes wrote:

> For the process of formation of complex carbon compounds out of simple ones under the influence of light, I propose that the term photosyntax be used. The protoplasm, by the aid of light, marshals the molecules into a new array and brings bodies of them together into new forms, as the individuals of an army are arrayed in companies, and companies drawn up into regiments. I have carefully considered the etymology and adaptation, as well as the expressiveness, of the word proposed, and consider it preferable to photosynthesis, which naturally occurs as a substitute. Its derivation is evident: *φῶς,* light; *σύνθεσις,* to put together, to arrange, to organize (pp: 409-410) .

Barnes's discussion is not limited to his emphasis on the role of light; it also explains the significance of "synthesis" as a process of putting things together. According to Barnes, "[p]hotosyntax is the synthesis of complex carbon compounds out of carbonic acid, in the presence of chlorophyll, under the action of light" (Barnes, 1893: 410).[53] He draws attention to

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[51] Assimilation described the production of organic matter by plants and the conversion of this organic matter digested by animals into the substances of their tissues (Gest, 1991).

[52] Such differentiation is a "demarcation question," in Evelyn Fox Keller's terms (2013). Fox Keller talks about the demarcation question in reference to the Lamarckian new ontology, which speaks to "the commonality of animal and plant life and their distinctiveness in relation to the non-living" (Keller, 2013: 15). Following her, the demarcation between plants and animals on the basis of photosynthetic potential provides another new ontology, different from the Lamarckian one.

[53] Barnes' emphasis on "synthesis" was not arbitrary. It was in line with the approach to the question of "what is life?" in the early twentieth century, "to be answered not by induction but by production," and "not by analysis, but synthesis" (Keller, 2013: 18). Such emphasis on "synthesis" at that time provides the earlier roots of contemporary discussions on artificial life, alongside synthetic biology (ibid: 20).

"chlorophyll," the biomolecule and colour pigment located within the chloroplast. These chloroplast organelles of cells are where photosynthesis takes place; they absorb light and use it to drive the synthesis of organic compounds from carbon dioxide and water (Campbell et al., 2009).

In 1837, French botanist Henri Dutrochet (1776-1847) recognized chlorophyll as an important factor. From that point on, the evolution of chlorophyll became a significant scientific question, not only to understand the emergence of photosynthesis on earth, but also in shaping evolutionary theories. In the early 1900s, Russian botanist Constantin Mereschkowsky (1855-1921) suggested that "chloroplasts, the organelles allowing plants to photosynthesize, were obtained initially from unicellular organisms that had been captured and 'enslaved' as endosymbionts" (O'Malley, 2010: 2015; also, see Sapp, 1994). Mereschkowsky also coined the term "symbiogenesis," a particular evolutionary theory proposing interspecies affinities as driving evolutionary change rather than, for example, neo-Darwinian emphasis on random genetic mutations. In the late 1960s, microbial ecologist Lynn Margulis (1938-2011) published the article, "On the Origin of Mitosing Cells" (1967), supporting Mereschkowsky's unrecognized hypothesis on symbiogenesis on the basis of molecular data. Her subsequent books, *Origin of Eukaryotic Cells* (1971) and *Symbiosis in Cell Evolution* (1981), revived the theory of endosymbiosis and suggested that cyanobacteria were the first producers of chlorophylls.

Penny Chisholm's narration of the discovery of *Prochlorococcus's* existence together with *Synechococcus* gestures towards the endosymbiosis theory of evolution. Until the 1970s, scientists believed that "all phytoplankton were between 5 to 100 μm in diameter," because this was all that could be seen under a microscope (Chisholm, 2011). With advances in microscopy, smaller cells of about 1 μm in diameter became visible to researchers. As Chisholm describes, *Prochlorococcus* was first named *Synechococcus*, but later "higher-resolution images of their populations revealed subtly different variants."[54] Chisholm writes, "[t]his could not be ignored":

> With growing affection, we began to call our newly discovered cells "little greens." Their detailed structure bore an uncanny resemblance to chloroplasts, the small oval bodies in plant cells where photosynthesis takes place, which are known to be evolutionarily derived from microbial cells through an ancient symbiotic union. No microbe had been identified that both resembled a chloroplast and contained the telltale chlorophyll b. *Had we found the missing link? Were our "little greens" living fossils?* (Chisholm, 2011, emphasis mine)

The missing link that Chisholm refers to is an evolutionary question: what is the common ancestor of all photosynthetic organisms' chloroplasts?[55] However, this is not the question that Chisholm continues to investigate. Rather, she has shown more interest in the biodiversity of "simple" endosymbiont life forms. As Chisholm (2014) notes, *Prochlorococcus* "embodies the minimal amount of information—2,000 genes—that generate life from solar energy and inorganic compounds":

> After its discovery we wondered how something so simple could be so ubiquitous, as general ecological theory would suggest such a system to be very unstable. The answer is, of course, that *Prochlorococcus* is not a single entity. It consists of unknown numbers of ecotypes, each with slightly different fitnesses along environmental gradients… The relative abundance of these ecotypes shifts slightly as ocean conditions shift, insuring the stability of "the collective"– or "*Prochlorococcus* federation" as we sometimes call it (p. 8) .

What interests me about Chisholm's story of *Prochlorococcus's* biodiversity is that the organism is represented as "the collective;" it is a "federation" that mostly co-exists with its "sister clade" *Synechococcus* (Chisholm, 2014: 7). Her use of the term "federation"—rather than the well-known biological term colony to indicate separate individual cells or organisms living together—

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[54] It was the technique known as flow cytometry that helped Chisholm and her colleagues to recognize *Prochlorococcus.* Flow cytometry is an experimental technique that was initially used in biomedical research and later on became a part of oceanographic studies. It employs a laser-based automated technology that counts and sorts cells by providing rapid measurements of single cell's chemical and physical properties.

[55] In the light of endosymbiosis theory, it is widely acknowledged that chlorophyll was first produced as "a cyanobacterial endosymbiont [… that] became integrated into the cell of its host, a heterotrophic eukaryote" (Green, 2011: 103). Yet, some of the details of this argument are missing—namely, which cyanobacterial endosymbionts are being invoked?

deserves attention. Both terms have political connotations. While "colony" refers to an area of settlement or a territory that has been claimed by one group through forms of violence that exclude others, the term "federation" denotes the "formation of a political unit from a number of separate states, provinces, or colonies" (*Oxford English Dictionary*). Accordingly, I read Chisholm's reference to *Prochlorococcus* as federation in line with her adoption of cross-scale systems biology as an approach that shapes her overall studies of *Prochlorococcus* from the genome to the global scale.

In line with philosopher of systems biology, Susan Oyama (2000a, 2000b), Chisholm is interested in the interdependence of organisms and environments in multiple complex systems. Instead of placing genes at the center of her analysis, Chisholm develops a cross-scale systems analysis that connects the study of ontogeny—the individual development of organism—with phylogeny—or the development of a species over time. In the Chisholm Lab, *Prochlorococcus* is studied "in all its dimensions," and rendered into a "model system" for understanding the ecology and evolution of microorganisms:[56] "The genomic and metabolic simplicity of these organisms…coupled with their abundance and intra-species diversity, make them an ideal system for understanding microbial metabolism and the origins and consequences of biological diversity." (Kelly et al., 2011: D632). Chisholm's systems approach to algal life seems to be shaped by the evolutionary theory of endosymbiosis, and this form of systems thinking can also be considered as a form of machinic rendering.

Systems biology is an "attempt to integrate data and ideas from several disciplines in order to explore questions that have not been answered by any single one." (Calvert & Fujimura, 2009: 49). As an interdisciplinary approach, it is part of "'postgenomic' knowledges that aim to

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[56] https://chisholmlab.mit.edu

provide ecological and 'holistic' understandings of life in lieu of the reductionist genetics" studies that dominated the life sciences by the 1960s (Fujimura, 2005: 195). The aim of this approach is to "provide a more rigorous and quantitative analysis" so as to solve the "problem of biocomplexity" (ibid: 197). As such, systems biology examines complex biological systems across "the machine-living organism border"—"where the representation of *biological systems and engineered systems are converging in a kind of symbiotic interaction*" (emphasis is original, Fujimura, 2005: 213). Likewise, Chisholm's research turns *Prochlorococcus* itself into a viable model system that postulates integrated understandings of ecology and evolution, as well as of metabolism and genetics. In the process, the boundary between "natural systems" and "artificial systems" becomes blurred.[57] In other words, Chisholm's modeling of *Prochlorococcus* is two-fold: not only does she instrumentalize *Prochlorococcus* in order to understand oceanic microbical lives, but she also re-produces the imaginations of ecology as a system, which the next chapter will further explore.

In sum, the previous sections showed that each time the story of evolution is retold, algae are themselves animated and reanimated. It is in this sense that algae are potentiated as functional, instrumentalizable, labouring, and accumulating organisms. These evolutionary narratives get tangled up together while simultaneously demarcating different components of life. For example, while the logic of cycling brings together elements of oxygen and carbon, the lives of photosynthetic and non-photosynthetic organisms also become interconnected. These imaginaries are not neutral; they are enactments (Barad, 2003). These enactments make some

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[57] Evelyn Fox Keller (2013) has noted that, "unlike mechanical and mathematical models," model organisms are "exemplars of *natural* models"; they are "not artificially constructed but selected from nature's very own workshop" (p. 59). In this regard, I claim that Chisholm's take on *Prochlorococcus* as a model system rather than model organisms is more in line with the artificial construction of mechanical models. For another line of discussion on model systems in relation to the way microbes come to fore as "good candidates for forming…model ecosystems," see Paxson & Helmreich, 2013: 168.

things visible and some stories salient, to the exclusion of others. These enactments also have temporal dimension. As we shall see, a return to origins of life via evolutionary stories is also "a journey into the future" (Helmreich, 2009: 12). In concluding this first section, I want to emphasize that researchers' potentiation of algae through evolutionary stories are also affectively charged. It is not only algae that get potentiated in these stories; researchers are also potentiated, by being made to feel responsible, in one way or another, for algae's future.

The Future

In her book *Beamtimes and Lifetimes* (1988), STS scholar Sharon Traweek narrates physicists' relations to time. Although Traweek's discussion of time is grounded in the specificities of her site and the cultures of physics laboratories she describes, her account of physicists' affectively charged relations to time is relevant to Chisholm's approach. According to Traweek, the past becomes insignificant when compared to physicists' anxieties in the face of a rapidly advancing future. Such anxiety involves a passion for static truths that need to be uncovered in order to transcend change and mortality. This passion is also a form of knowledge. I recalled Traweek's findings when I learned how much *Prochlorococcus* excites Chisholm. Similar to the physicists in Traweek's study, Chisholm finds herself motivated by her anxieties and passions to "invad[e] the inner life of [a] tiny cell that had drifted unnoticed in the oceans for millions and millions of years." Chisholm writes, "[m]y feeling grew into a sense of responsibility—a need to bring it the respect it deserves. One does get attached" (Chisholm, 2011). Chisholm's passion for studying *Prochlorococcus* is linked to her anxiety about contemporary geoengineering projects that threaten life in the oceans:

> I am reminded that while they [*Prochlorococcus*] carry out a respectable fraction of the photosynthesis on our planet, they escaped our attention until a few decades ago. What else of this magnitude are we not seeing? Will we find it before human activities have completely dominated the oceans, as they have the land? As I write this, commercial ventures are gearing up to fertilize the oceans to trigger phytoplankton blooms, designed to draw carbon dioxide out

> of the atmosphere to abate global warming. If carried out on grand scales this approach would, by design, dramatically alter the marine food web. I have repeatedly voiced the position that commercialized ocean fertilization is an ill-advised climate mitigation strategy. Some have argued, only partially in jest, that my protests are simply a disguised concern for *Prochlorococcus*. On the contrary, these tiny cells occupied our planet long before humans, and they will surely outlast us. They can photosynthesize. They thrive through diversity. Their federation can adapt. And, as one of my graduate students once put it, they have a time-tested strategy: "grow slowly, and endure" (Chisholm, 2011) .

Chisholm is passionate about "invading the inner life of a cell," and becomes anxious in the face of geoengineering projects. She is aware of the politics of these projects, and feels responsible. In reformulating Karen Barad's notion of responsibility, feminist technoscience scholar Astrid Schrader (2010) explores the question of feeling responsible in relation to living organisms' ability to respond, or their "response-ability." Schrader argues that, "getting the experiments to work responsibly and repeatedly requires attention to the agencies of the object of study […] which in turn necessitates the inclusion of particular matters of concern […] as part of the objective referent, which also establish the ecological and political relevance of the experiments" (Schrader, 2010). For Schrader, responsibility is about the enabling and disabling of responsivity between the "object[s]" and "agencies of observation" entangled in experimental configurations. What I hear in Schrader's account is that researchers are not only potentiating algae in their experiments. The researchers themselves are also potentiated as they learn to respond to algae through their experimental practices and stories.

For Chisholm, *Prochlorococcus* have been made response-able to biogeochemical changes by growing slowly and thus enduring despite these changes. Geoengineers are response-able for climate change; they respond to climate change by fertilizing the oceans to enable fast algal growth. Chisholm situates herself as response-able to activities of both humans and more-than-humans in oceans by accelerating her research, and, particularly, by enabling *Prochlorococcus* as a model system. In this regard, the response-abilities of Chisholm, geoengineers, and organisms are shaped by one another. These conjoined responsibilities make it clear that STS scholars need to pay attention to the politics of these relations. And, as the next section will elaborate, I suggest this can be done by tracing how researchers intervene in algal reproduction processes through their experimental practices. It is through these practices that researchers potentiate algae with specific political effects.

In sum, the first section has shown that neither algae's photosynthetic potential, nor photosynthesis itself are natural phenomena. Rather, the evolutionary tales of algal photosynthesis potentiates algae as energetically labouring and accumulating organisms. These stories have also rendered photosynthesis workable for an economically productive view of ecology. In order to grasp how economic logics are prefigured inside of the life sciences, it is important to see how an "energetic fallacy" reduces algal photosynthesis to its role as an omnipresent energy provider. This point is especially salient for understanding how oceanic ecologies become imagined as abundant and ubiquitous, and potentially profitable resources for fossil fuel and renewable energy markets.

The second half of this chapter will turn to the experimental lives of algae in order to explore how researchers render algae in aggregate form to serve as biomass for bioenergy economies. With this analysis, I demonstrate how algal photosynthesis comes to fore as an economic question of efficiency and productivity. I will draw attention to historical correlations between the rise of concerns about efficiency in photosynthesis research, and initial efforts for the mass cultivation of algae. The link between photosynthesis research and algal cultivation introduces another story of algal biofuels, one that sheds light not only on how algae's photosynthetic capacity is naturalized, but also, how it is also worked on, manipulated, and even eliminated in efforts to go beyond the "limits to efficiency."

Experimenting with Algae or Photosynthesis?

In 2007, Yusuf Chisti, a professor of biochemical engineering at Massey University, New Zealand, published an article, “Biodiesel from Microalgae.” At the time of writing, biodiesel from oil crops, waste cooking oil, or animal fat was already in manufacturing processes, on the market, and in automobile gas tanks. Microalgae mostly languished in laboratories, waiting for their turn to be commodified into biodiesel. Among other latecomers, Chisti drew attention to microalgae as the “only source of renewable biodiesel that is capable of meeting the global demand for transport fuels” on the basis of algae’s photosynthetic “potential” (Chisti, 2007: 294).

The question of algae’s photosynthetic capacity had been subject to algal research long before its appearance in biofuels studies research. It arose alongside initial research into systematic photosynthesis, a field of study developed by the German cell physiologist Otto Warburg (1883-1970). Warburg was the first scientist who introduced algae, specifically *Chlorella*, to experiments measuring photosynthetic efficiency. Before Warburg, scientists had been using the leaf tissue of higher plants as a material of choice (Nickelsen, 2009; Zallen, 1993b). Warburg’s work made the connection between photosynthesis and algal research. As I reviewed the history of research in these fields, I realized that there is an interesting correlation between the rise of the efficiency question in photosynthesis research and the mass cultivation of algae as feedstock during the 1940s.[58] This history pushed me think further about the question of efficiency in algal biofuels research. The second half of this chapter will explore this question.

Warburg's experiments with algae in photosynthesis suggest that one specific species of algae—*Chlorella*—had already been domesticated as a laboratory organism before biofuels research. Warburg was measuring gas production and consumption by living photosynthetic organisms. The diffusion of gas in the interior layers of leaf tissue before it exits the tissue prevented him from gaining accurate measurements (Zallen, 1993b: 271). He wanted a material that could do the job, one that had "rapid growth, lack of mobility, and a simple developmental cycle," in addition to carrying out photosynthesis (Warburg 1919: 231, cited in Zallen, 1993b: 271). It was *Chlorella pyrenoidosa* that helped Warburg to achieve an accurate measurement of gas reactions during photosynthesis.

Warburg was not only interested in the inputs and outputs of the photosynthetic process, but also in the efficiency of the process—specifically, light quantum requirements (Nickelsen, 2009: 73).[59] For Warburg, the photosynthetic potential of organisms was principally dependent on light intensity, light absorption processes, and secondary chemical reactions (Nickelsen, 2009: 77). According to Warburg, providing a detailed understanding of photosynthesis beyond one-step-models was essential. Warburg's studies on the process of converting sunlight into chemical

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[58] Some researchers, such as the former president of the International Society for Applied Phycology (ISAP), Prof. Johan U. Grobbelaar, have drawn attention to the link between algal and photosynthesis research. Grobbelaar has noted that the "maximum photosynthetic efficiency (energetic efficiency) and the upper limits of photosynthetic productivity have since the early days been central to the mass cultivation of algae" (Grobbelaar, 2010: 135-136). He suggests that the questions of photosynthesis efficiency and productivity developed in line with the mass cultivation of algae by World War II, in the 1940s. The report—*Algal Culture: From Laboratory to Pilot Plan* (Burlew, 1953)—published by the Carnegie Institute of Washington, which undertook algal research at the beginning of the 1950s, supported Grobbelaar's emphasis on the relation between the mass culturing of algae and photosynthesis research.

[59] He experimented with measuring the minimum number of light quanta necessary to produce oxygen in photosynthesis. He and his coworkers found that the minimum number had to be four quanta (Zallen, 1993b: 272). Robert Emerson later claimed that algae needed a minimum value of eight to twelve quanta to make oxygen; similar values are still accepted today (Wozniak et al., 2002).

energy provided new understandings of the physicochemical processes and efficiency of photosynthesis.

STS scholar Doris T. Zallen (1993a, 1993b) has noted that while the process of photosynthesis had been known for approximately two hundred years, understandings of this process were superficial before the *Chlorella* era. In early views plants were seen to "convert carbon dioxide and water into organic matter" in "the light and in the presence of the green chlorophyll pigments," synthesizing carbohydrates and releasing oxygen (Zallen, 1993a: 70). In the era of *Chlorella*, photosynthesis was transformed into an analysis of bioenergy. By the 1920s, photosynthesis research had developed within the framework of bioenergetic studies that established connections between physical chemistry and the life sciences. Exploring the conversion of light energy into chemical energy, as well as the production of carbohydrates, physical-chemical models became important. Moreover, the photosynthetic potential of organisms came to be evaluated in terms of their efficiency in converting sunlight into chemical energy. What I hear in stories like Warburg's is that experiments on photosynthesis paved the way for researchers to imagine and work on algae as biomass. These experiments illuminated how algae could be cultivated for efficient and productive bioenergy economies. This is especially evident when I reviewed new meanings of the term "bioenergy."

By the 1970s, the concept of bioenergy was popularized in reference to energy produced for industrial and domestic use. This etymology is traceable through a succession of bioenergy definitions in the *Oxford English Dictionary*. Furthermore, biomass, the scientific and ecological term used to connote the measurement of the total mass of all living things, emerged as "shorthand for non-fossilized biological material, particularly plant matter that can be used as a feedstock for fuel or for industrial chemical production" (ETC Group, 2010: 6). The recent popularization of the terms bioenergy and biomass in relation to discourses of energy-as-resource inscribes a shift in humanity's relationship with plants—in short, these terms tell us what the bioeconomy does to life:

> Unlike the term "plant," which indicates a diverse taxonomic world of various species and multiple varieties, the term biomass treats all organic matter as though it were the same undifferentiated "plant-stuff." Recast as biomass, plants are semantically reduced to their common denominators so that, for example, grasslands and forests are commercially redefined as sources of cellulose and carbon, in this way biomass operates as a reductionist and anti-ecological term treating plant matter as a homogenous bulk of commodity (ETC Group, 2010: 6) .

In 2010, the ETC Group[60]—an action group that explores new technologies on the basis of their socio-economic and ecological impacts—published a report entitled, *The New Biomassters.* The report discussed the replacement of fossil carbon economies with "biomass" economies. I draw attention to how the term biomass—as well as its related economies—reduces the biodiversity of plants to their constituent parts, notably, cellulose and carbon. In other words, when plants are included in the biomass sector, they are no longer plants exhibiting biodiversity, but become, for instance, resources to be mined for carbon or cellulose. Here, the photosynthetic potential of algae has come to signify, for example, the potential of algae-produced lipids.

In the light of this report, I offer a story of algae's experimental lives in which algal photosynthesis gets potentiated in artificial environments, such as test tubes. I will demonstrate how experimental interventions into algal reproduction processes make algal photosynthesis efficient, productive, and thus economically valuable. By drawing attention to the techniques and technologies that researchers employ to grow algae, I show that cultivating algae as potential bioenergy resource not only hinges on efforts to go beyond the "limits to growth" (Cooper, 2008), but also seeks to go beyond the "limits to efficiency." Further, I draw attention to the

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[60] For further information, see: http://www.etcgroup.org

ways that researchers fetishize the concept of efficiency to such a degree that the photosynthetic potential of algae becomes secondary to its profits. In other words, if algal photosynthesis is no longer economically viable, researchers may choose to bypass it in order to generate economic value by other means. I begin this story of algae alongside Mira, with whom I learned how to "grow" algae in test tubes.

Growth

November 2015, Chisholm Lab. It was a bright and early morning as I walked gingerly into the lab incubator furnished with rows of artificial lights and fans. Carefully taking hold of several test tubes of cyanobacteria cultures, I placed them one by one on a vortex shaker to mix them. Once complete, I moved the test tubes into a chlorophyll fluorometer to count cells—this was so that I could measure the photosynthetic performance as well as growth rates of a number of cyanobacteria strains. I waited for the numbers on the screen to stabilize, and as the results emerged before my eyes, I carefully jotted down the numbers onto the computer's open Excel spreadsheet. This is one of the techniques I learned during my eight months in the Chisholm Lab at MIT. I was assisting Mira, one of Chisholm Lab's PhD students, with an experiment she was conducting to determine high light shock toleration of specific strains of cyanobacteria.

Mira developed a PhD project that explored the role of light in the evolution of diversity in particular cyanobacteria strains, namely *Prochlorococcus* and *Synechococcus.* She was curious of how specific strains' light shock tolerance was related to their genetics. She staged an experiment to answer one particular question: which strains of cyanobacteria can tolerate high light shocks occurring in oceans through temperature changes? Light shocks are a "natural phenomenon," as Mira explained. They happen in oceans as a result of temperature differences. She gave me an example: Storms cause a vertical mixing in the oceans, an upward and downward movement of water. Cyanobacteria adapted to living in the deep ocean move upward. Thus, these "collectives" living under conditions of low light intensity in the ocean's deeper layers are exposed to higher intensities while moving upward to the ocean layers close to the surface. Such movements happen suddenly, resulting in the rapid exposure of algae to light.

Mira built an artificial environment—what I call a *built ecology*—in a laboratory space to simulate these organisms' "natural environment." In this artificial environment, evolutionary stories are different from Chisholm's "just-so stories" (Stephen Jay Gould) of algal photosynthesis, where evolutionary narratives explained the functional role of algae in productive ecologies. If Chisholm's evolutionary narratives naturalize the function of algal photosynthesis in oceanic ecologies imagined as closed ecological systems, what do Mira's experiments teach us about the photosynthetic potential of algae? How does Mira's staging of an experiment with cyanobacteria in the form of laboratory cultures potentiate these organisms' economic potential? How are the imaginations of ecology as a closed system linked to the artificially built ecologies in lab spaces?

There is much at stake in these questions. Mira wanted to mimic the natural growth state of cyanobacteria as part of oceanic ecologies with her experimental design. She aimed to understand how specific strains of cyanobacteria survive light shocks through simulating an oceanic ecology in test tubes. Yet, Mira's experiments were not only about highlight shock tolerance capacity of different strains of cyanobacteria indicating their photosynthetic efficiency. As Mira told me in our first meeting, this experiment was related to my research on algal biofuels because maintaining "continuous growth" rates and selecting strains on the basis of their light absorption potential lies at the heart of cultivating algae as biomass. In other words, the growth potential of algae under particular illumination rates specifies the economic potential of algae as biomass to be converted into a bioenergy resource. During my laboratory work alongside Mira, I had the chance to see how designing and staging experiments would potentiate algae as biomass with economic value.

The cultures Mira used for her experiment were already rendered as technologies "to do things that humans value but they might not have done in nature" (Kohler, 1994: 6; see also Landecker, 2007). These *Prochlorococcus* cultures had been already domesticated as laboratory organisms, and designed as a model system in the Chisholm Lab. As Kohler reminds us, these domesticated experimental creatures have their own politics (Kohler, 1994: 8). Above, I discussed the politics of Chisholm's evolutionary narratives, which render these organisms as machinic labourers that function in productive ecologies. Here, in the laboratory environment with Mira, these organisms enter a new "symbiotic relationship with humans, as participants in experiments," and this experimental configuration teaches us something new about the politics of stories of life and growth in algae research (ibid: 5). What are the political stakes in the stories of "continuous growth" that Mira tells? To explain how Mira crafts both a built ecology and creates a "state of continual growth" for her algal cultures, I will explore how she sets up her experimental configuration.

For her experiment, Mira initially set up a temporary place in an incubator, a rectangular room no larger than 3 meters by 5 meters. She was temporarily using this incubator, as she planned to undertake her light shock experiment in a larger incubator. The larger incubator, however, was in use by the other members of the lab, and it was not suitable for her light shock experiment. Making do with the resources available to her, Mira instead decided to modify the smaller incubator environment to suit her experiment's needs. Before beginning the actual experiment, she first needed to increase the incubator's available lighting. To do so, Mira ordered several “spotlights,” or florescent tube lamps, to correct this problem. However, as a result, she was left with another challenge, the problem of overheating. The introduction of new lighting brought with it changes in the incubator’s temperature level. As the lamps co-generated light and heat, Mira had to find a workaround that would offset the heat increase in the incubator without sacrificing the lamps’ light output necessary for her experiment. Working together, Mira devised a plan to use a series of small, portable fans to solve the heating problem. Content with her workaround, it was time for Mira to *acclimati*ze the algal cultures to their new environment.

Acclimation, as Mira told me, is different from adaptation. It was the first time that I heard this concept. Mira kindly corrected me every time I used the term adaptation. Acclimation refers to the adjustment of cells’ phenotypic properties to changing conditions, mostly in artificially built environments. Adaptation is different; it is about the evolution of genotypic properties over a longer time-span, mostly in natural environments. In other words, the term adaptation refers to the changes over generations in a population, while acclimation is limited to specific strains’ lifetime. The aim in Mira’s experiment was to grow particular cyanobacteria cultures acclimated to the artificial environment in the incubator prior to the shock treatments.

It took approximately two months for Mira’s cultures to grow in the incubator, illuminated by white fluorescent lamps at around 21^{o}C. Different strains of *Prochlorococcus* and *Synechococcus* were arrayed in test tubes labeled with various colourful stickers carrying Mira’s initials, the name of the strain, and the date indicating when the culture had been prepared. These strains were growing, but not continuously. For Mira, they had to grow as continuously as they do in their “natural environments,” in other words, in the oceans. These strains as laboratory cultures had to become acclimated to the new artificial environmental conditions set up in the incubator. Mira explained what she meant by continuous growth with the help of two charts she drew for me on a small piece of paper (Figure 3).

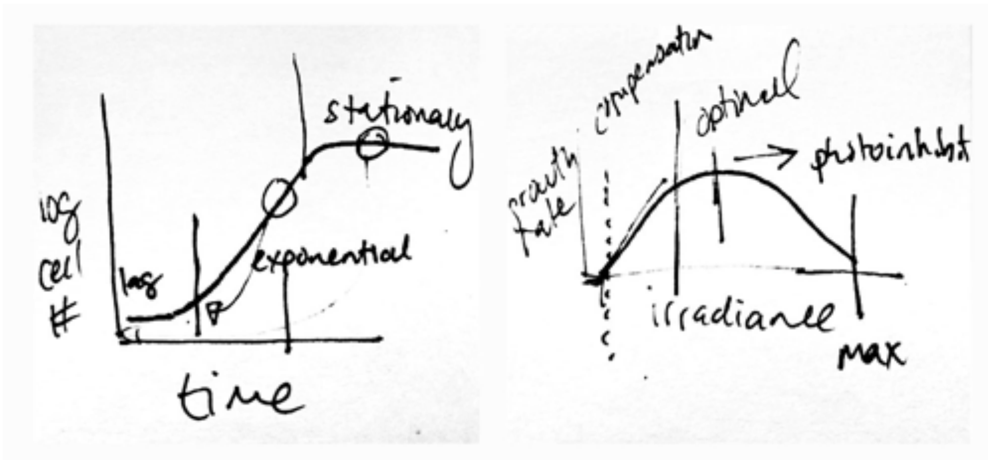

Figure 3 Growth Charts
Photo of Mira's drawings taken and edited by the author. Mira explains the growth of laboratory cultures in the test tubes that changes by time and illumination rates.

The chart on the left provides information about the changing number of cells over time. After an exponential increase in cell numbers, the growth stops and moves into a stationary phase.[61] The reproduction of cells in test tubes signifies the growth dynamics of cultures. The algal cells subject to Mira's experiment reproduce themselves by division, also known as binary fission. In theory, microalgae cells—including cyanobacteria—double every day.[62] Thus, when Mira talked about continuous growth, she was referring to the doubling of cells each day. She measured the growth rates through counting cells. Back in the lab, Mira continued reading the chart on the right. This chart also explains the growth rate, but on the basis of changing light intensity levels. I learned from Mira that there are optimal illumination rates for cell cultures to absorb, and these rates differ by strains.

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61 The term stationary phase refers to the state when growth rate and death rate in a cell culture are equal. It points to factors that limit growth rates, such as, nutrition depletion.

62 Doubling time ranges by species and/or strains. For example, "the doubling time of some *Chlamydomonas* species is as short as six hours" (Chen et al., 2009: 3).

Over two months, Mira and I assessed whether the cultures subject to the experiment grew continuously as we varied the parameters of light intensity, growth rates, and growth time. We were waiting for what Mira called "beautiful lines" to appear on the computer screen. For Mira, these beautiful lines represented cultures growing continuously over time and without any stationary phases. As Orit Halpern has explored in her book *Beautiful Data* (2015), the label "beautiful" is not neutral. It speaks to the aesthetics that craft a phenomenon—growth, in this case—as useful; it is "a performance necessary to produce value" (Halpern, 2015: 5). Mira was trying to craft "beautiful lines" by directly intervening into the cultures growing in the test tubes. In these built ecologies, continuous growth was not possible, as her graphs above indicate. Yet, to mimic the continuous growth of "collectives" in oceans, she was intervening in the reproduction process of algae cultures in the lab. With Mira, I learned that the limit for cyanobacteria cultures' continuous growth depends on the volume of the test tubes in which these cultures need to grow in order to get ready for the experiment. I realized that the cultures in the test tubes required Mira's ongoing interventions to be able to grow continuously, or to become viable cultures for the experiments. I developed these insights while trying my hand at techniques in the laboratory and helping Mira as she prepared the cultures for her light shock experiment.

The first technique I learned was how to measure light intensities exuding the tubes filled with different cyanobacteria cultures and standing altogether in their colourful test tube racks in the incubator. The light sensor device was our main instrument for this measurement. The light sensor informed us about the rate of illumination (ambient light), where the center of the culture would sit in terms of quanta. The aim of this measurement taken prior to the shock experiment was to be sure that light intensities were at the required levels (27 ± 2 μmol quanta m^{-2} s^{-1}).[63] In other words, we were measuring whether light energy in the incubator was at the level required for Mira's cultures to photosynthesize, grow, reproduce, and acclimate.

Image 1 The author working at the lab.
Photo by Mira

Immediately after measuring the light intensities, we took the cultures in their tubes out of their tube racks, one by one, in order to measure the growth rates. With the help of the vortex shaker, the cultures in the tubes were mixed; the cells were suspended to allow for a precise measurement. Mixing was an important part of the experiment: it "implies moving liquid in a tube," and "the degree of mixing directly determines the resultant turbulence" (Grobbelaar, 2010). We then placed test tubes into the chlorophyll fluorometer, as the machine that takes measurements to assess photosynthetic energy conversion. We took these measurements every day in order to determine whether the cultures became acclimated to their new environment or not. However, Mira had to wait for the acclimation of cultures. She intervened in the growth process through another technique while waiting.

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[63] "Illumination for plants, also known as 'irradiance', is sometimes measured in PAR watts per square meter (W/m^2). Another means of measuring light quantity for plant growth involves discrete units of quantum flux in the PAR region called 'photons.' Photon flux is commonly measured in units of micromoles per square meter per second ($\mu moles/m^2/s$), where 1 mole of photons = 6.022 x 1023 photons"
[(http://www.egc.com/useful_info_lighting.php), accessed by March 2016].

The other technique I learned was transferring cultures—that is, refreshing the media in which cyanobacteria cultures grow to ensure that they have enough nutrients and room to grow. The aim of transferring was to avoid a stationary phase and keep cultures growing as continuously as possible. Examining the monitored growth rates, Mira had to decide on the timing of the transfer. After a week or two she would transfer the cells. This practice, also known as splitting, subculturing, or passaging, required Mira to work in a biosafety cabinet as she carefully pipetted approximately 1 ml of algal culture from the existing test tubes into new media of a volume of 20 ml. She diluted cultures by transferring them into "fresh media" made from seawater, brought to the laboratory from the Sargasso Sea, and a variety of chemical nutrients.

When Mira obtained her "beautiful graphs of growth," she thought that she had successfully simulated the "natural" environment of her cultures. She imagined "continuous growth" as a possibility in closed, built, environments. However, Mira herself, whether she realized it or not, was also part of the artificial environment that she designed and built for her experimental cultures. Mira occasionally referred to the graphs that represented the growth states of her algae cultures as if they represented the growth of organisms in oceanic ecologies imagined as closed systems with limited resources. As I observed her work, I realized that telling stories of ecologies as closed systems is related to the limits researchers encounter in these artificially built ecologies. In this sense, experimental designs and laboratory practices participate in shaping imaginaries of "natural" ecologies as closed, nutrient limited systems.

Mira began staging the light shock experiment when the cultures were ready, growing nearly continuously. She moved cultures to the "high" light space (with an illumination rate of 300 ± 15 μmol quanta m^2 s^{-1}) in the same incubator and kept them there for four hours. The light quanta were approximately 10 times more than the space where the cultures had acclimated.

Mira was testing whether the cultures exposed to shock would recover and how they did this. In the end, she found that different strains have different capacities to withstand dramatic and transient increases in light. In a larger context, Mira drew a number of conclusions regarding the relationship between genomic variation and light physiology.

Mira's efforts to build an ecology for her experimental cultures already economized cyanobacteria before these organisms are enrolled into the bioenergy markets in the form of commodified biomass. In other words, Mira was not only simulating "continuous growth" of cyanobacteria in oceanic ecologies, but also crafting continuous growth as phenomenon by intervening into the reproduction process of algal cultures. She was intervening right before the moment her cultures were about to die. She bred culture cells in the test tube—some of which made their way into pipettes, while other cells died off—eventually making their way into the laboratory's sink after being bleached (so as not to escape out of the laboratory). What mattered to her was not individual cells, but instead the continuity of an acclimated, domesticated, and naturalized culture in its new artificial environments.

Working alongside Mira, I came to recognize that her experimental efforts to grow algal cultures continuously in tests tubes were a way of generating value. Yet, the more I engaged with different experimental practices related to algal biofuels, the more I realized that "continuous growth" is not the only matter of concern; what also matters is the efficiency of algal photosynthesis. I now turn to Halil Kavaklı's experiments to explore how algae get potentiated as "efficient" and "productive" forms of biomass for biofuels production.

Efficiency

Imagine how algal biofuels researchers might scale up algal cultures. What could replace Mira's experimental transferring technique to obtain "continuous growth" in larger containers? It is a question that Prof. Halil Kavaklı raised in a different way at an algal biofuels seminar held at Boğaziçi University (Istanbul, Turkey) in June 2016.[64] Before stepping into algal biofuels research, Kavaklı conducted extensive research to identify the main problems preventing the scaling up of algal biofuels research from laboratory to industrial production. He determined that "one of the biggest challenges in biofuel research is obtaining biomass substantially." In Kavaklı's research, algae are already figured as biomass and Mira's concern about "continuous growth" is instead replaced by the challenge of obtaining a substantial amount of algal biomass. Kavaklı claims that it is not possible to obtain the required algal biomass by maintaining the optimal growth conditions for algae. His suggestion tells us a story different from Mira's experiment:

> Algae are living beings. It does not matter how you maintain the ideal conditions, it may not do what you want it to do. It may do so, but not quite; around 2-5 percent, but no more than that. Why? Because there is the genetic code…Now, you say to the organism: I have maintained ideal conditions for you, now you produce lipid for me. It doesn't produce any. Why? Because the processes of what to produce and how much are already genetically coded. So if you do not consider the genetic side of the question, it does not matter how much you play with these parameters.

To Kavaklı, maintaining ideal conditions means "playing with" the following variables: light intensity, cultivation medium or nutrients, carbon dioxide, pH, aeration, and mixing. These were the same parameters Mira played with as she transferred her experimental cultures from one test tube to another in her light shock experiment. Yet, Kavaklı notes that, when similar efforts to grow algae move from the laboratory scale to the "factory floor," playing with these parameters is not only insufficient, but also expensive. The solution then lies in genetics:

> The cell grows, but not sufficiently. By using my area of expertise, we have worked on the question whether we can increase cell biomass. Our aim is increasing microalgal biomass by using classical mutation techniques… We have produced a number of mutants that produce more oil while growing faster in comparison to the wild strains.

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[64] "Biofuels from Microalgae and Bioenergy Applications" (June 27th, 2016).

While employing mutation techniques on algae to increase cell biomass, Kavaklı's project team worked with the microalgal species *Chlorella vulgaris.* Kavaklı explains the reasons behind his choice: First, *Chlorella vulgaris* can grow very rapidly in comparison to other microalgal species. Second, it is robust in the face of various environmental changes. Third, its lipid content is greater: "Although the literature cites numbers such as 60 percent and 40 percent lipid content, in our lab, we have seen maximum 30 percent." Fourth, it can produce saturated and unsaturated fatty acids. Lastly, they can produce several valuable molecules, such as β-Carotene. In sum, the photosynthetic potential of *Chlorella vulgaris* is suitable for an experiment that aims to create mutants—mutant strains with economic potential given their rate of growth and their scalability in the production of high-value-added products in addition to lipids for biofuels production. Kavaklı continues by presenting how the cell looks under an electronic microscope (Figure 4): "There is the nucleus, chloroplast and mitochondrion. What you see here is lipid. Actually, there is nothing except lipid."

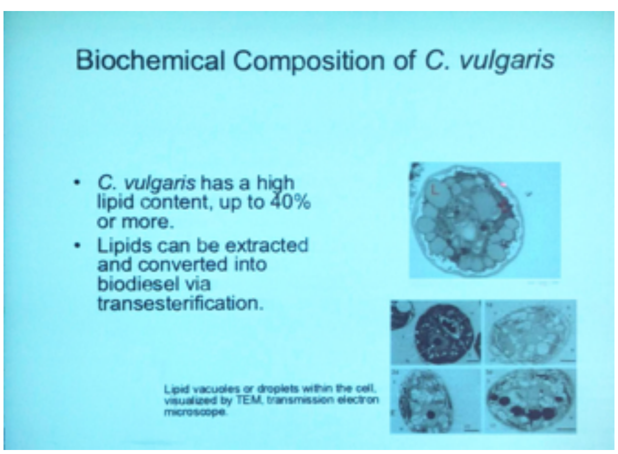

Figure 4 Lipid content of cells
Photo taken and edited by the author. From Kavaklı's presentation, the slide reads "Biochemical Composition of C. vulgaris." Kavaklı showed this slide to express how high the lipid content of the algal strain c.vulgaris.

After drawing the audience's attention to a cell image, Kavaklı begins explaining the details of their experiment with *Chlorella vulgaris* that aimed to create mutants that "produce more oil while growing faster in comparison to the wild strains." He gestures towards a well-known "trade-off" in algal biofuels research: the lipid content of cells decreases when they grow continuously. In other words, algal cells produce lipid under stress conditions, for example, while lacking sufficient nutrients (such as nitrogen and phosphate) or high light intensity (Mujtaba et al., 2012; Rismani-Yazdi et al., 2012). In the literature on algal biofuels, scientists discuss these conditions as "regimes," connoting what regularly happens. For example, they talk about nitrogen and phosphate regimes and a light regime. Accordingly, they acknowledge that algae have adapted to live under specific conditions. Yet, when it came to the question of not "merely living," but growing for mass cultivation, researchers began probing the photosynthetic efficiency of algae.

What do researchers mean by efficiency? Although there are "many different types of efficiencies discussed in the literature," researchers overall refer to photosynthesis as a solar energy converter (Schneider, 1973). The discussions about and research on different forms of efficiencies are subject to the question what researchers aim to do with algae, or what they want algae doing: for example, the efficiency of algae in carbon sequestration (Rosenberg et al., 2008), storing oil (Moellering & Benning, 2010), or in producing numerous metabolites (Boyle & Morgan, 2009). Despite these differences, algae's photosynthetic efficiency connotes "the ratio of the free energy of the biomass produced." The question, therefore, becomes one of "determining the maximum growth yield from the available light energy" (Pirt et al., 1983). This specific understanding of efficiency is historically situated.

By the 1950s, the "mechanisms" of energy conversion was among one of the leading questions in photosynthesis research conducted through the increasing collaboration between plant physiologists, physicists, and chemists. At that time, biophysics and biochemistry preoccupied the life sciences, as did the question of photosynthetic efficiency (Huzisige & Ke, 1993). Although it was debatable whether or not thermodynamics would be helpful for understanding photosynthetic energy conversion, it shaped photosynthesis research alongside the question of "limits to efficiency."[65] The application of thermodynamics in photosynthesis research underlined that the organisms' photosynthetic potential cannot be limitless; rather, there is a maximum efficiency for the conversion of sunlight into chemical energy.[66]

The legacy of these early discussions is traceable in contemporary algal biofuels research. For example, Ted Patzek, a professor in the Department of Petroleum and Geosystems Engineering at the University of Texas, Austin, explains why algae cannot solve "the runaway problem of energy consumption": "The reason is simple, the laws of nature, specifically the First and Second Law of thermodynamics, do not allow for the sustained production of energy from plants in [one] year at the same rate as we have been using fossil energy accumulated over 500,000,000 years" (Leonard, 2007). Overall, the "limits to efficiency" connotes the limits of the energetic potential of photosynthetic organisms—in other words, the limits to the economic value of energy produced and extracted, for example, in the form of lipids. These studies on the application of thermodynamics to algae-based photosynthesis research are indicative of the ways that algal cells became "algal motors," in historian of science Anson Rabinbach's (1992) terms.[67] Thus, the application of thermodynamics to photosynthesis research must also be understood as politically and economically situated.[68]

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[65] For a further discussion the applicability of thermodynamics in photosynthesis research, see for example, David Kahn's (1961) critique.

[66] The primary example of a study that discusses the physics underlying the photosynthesis process is Louis Nico Marie Duysens's doctoral thesis written in 1952, entitled *Transfer of Excitation Energy in Photosynthesis*.

[67] In his book *The Human Motor*, Rabinbach traces how "energy" becomes the universal principle of work in the nineteenth century, alongside the rise of thermodynamics. The science of work based on "energy conversion" theories shifted understandings of work, from a socio-economic activity to an "economy of force" and replacing labour with labour power. To Rabinbach, the thermodynamic approach to work constituted the beginning of the modern productivism that still haunts the present.

[68] Thermodynamics as an object of study lies beyond the scope of this research. There exists voluminous STS literature that explores the historical shape and effects of thermodynamics not only on our perceptions of life, but also on particular disciplines such as economics (e.g., Barry, 2015; Keller, 2003; Mirowski, 2002; Rabinbach, 1992).

Nevertheless, against the claims for the "limits to efficiency," some researchers like Kavaklı acknowledge that "[i]f any process is not feasible thermodynamically, it can never be used in the real world." This suggests that "[i]f the limits offered in thermodynamic analysis cannot be attained immediately with the present technology, they may still be used to understand the area where new technology is needed" (Sorguven & Özilgen, 2010). Here, research to improve algae's contemporary productivity continues through metabolic, genetic and systems engineering methods. These methods are relatively different from the efforts of the 1960s (Oswald & Golueke, 1960; Sculthorpe, 1967), which focused more on environmental engineering and ecophysiology, or what Kavaklı calls "playing with parameters."

Factors limiting photosynthetic efficiency come to mean limits to potential production (Beadle & Long, 1985). Factors limiting photosynthetic efficiency and, thus, the productivity of algae are evaluated in two groups: (1) the limits to efficiency that directly depend on algae's potential for light harvesting or respiration; (2) environmental influences such as light, temperature, water, and nutrients (ibid.). Kavaklı believes that "playing with parameters," or controlling environmental influences, is not sufficient for obtaining the required algal biomass (2). He suggests working "directly" with mutated algal cells in order to overcome the "limits to efficiency," or the limits of algae's photosynthetic potential for producing algae as biomass (1). At this point, I ask: How do algal biofuel researchers talk about, and contend with, factors limiting the photosynthetic efficiency of algae in energy storage? The next section will open this question by comparing algal photosynthesis as a technology with solar panels, and exploring how researchers intervene in the evolutionary timescale of algal photosynthesis to enhance their productivity and value in bioenergy economies.

Productivity

> Solar energy, reaching the surface of the Earth at a rate of approximately 120 000 TW, is a sustainable resource exceeding predicted human energy demands by >3 orders of magnitude […] Globally, the process of oxidative photosynthesis […] stores solar energy in the form of reduced carbon compounds at a rate of approximately 120 TW […] Compared with synthetic solar panels with reported 30% efficiencies, photosynthesis has a maximum efficiency of 8-10%.
> (Stephenson et al., 2011: 615-616)

The quote above sparks an interesting provocation: to what extent can solar energy storage technologies such as synthetic solar panels and photosynthesis meet human energy demands? Algal biofuel scientists Stephenson and his colleagues frame photosynthesis as a problem of energy storage and question the efficiency of photosynthesis in comparison to solar panels. While algae are considered to be more productive than, for example, terrestrial plants in the conversion of solar energy into lipids (Dismukes et al., 2008; Weyer et al., 2010), when algae are compared with solar panels, they are deemed inefficient.

The basic claim is that the intensity of sunlight exceeds the photosynthetic potential of living cells, and that this poses a limit on achieving high photosynthetic efficiency in algal cultures (Mooij et al., 2015). Energy apparently gets lost during the conversion of sunlight into biomass (Wobbe & Remacle, 2015). Sunlight in this frame is rendered as an excess, and excess light energy is wasted, dissipating as heat. Such energy loss decreases "the light use efficiency of the [algal] culture" (Mooij et al., 2015). Stephenson et al. (2011) have explained the process of photosynthetic solar energy conversion by means of the figure below (Figure 5), entitled "Improving photosynthesis for algal biofuels: Toward a green revolution." This figure focuses on the efficiency of the conversion of solar energy into lipid: "The stages indicated by yellow arrows need to be maximized and the loss terms indicated by purple arrows need to be minimized" (Stephenson et al., 2011). Although a detailed discussion of this figure is beyond the scope of this research, it shows how algal biofuels scientists locate algae's so-called inefficiency in the process of converting solar energy into lipids.

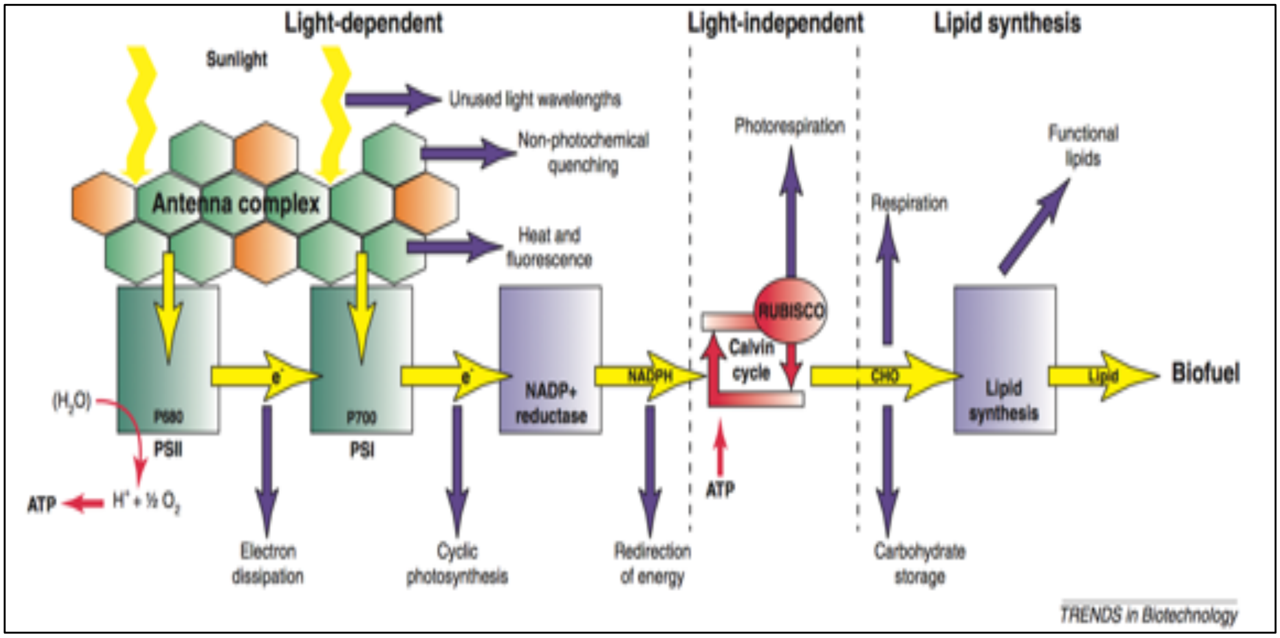

Figure 5 Photosynthesis in "the inner life of cells"
Screenshot from the article of Stephenson et al. (2011). The authors use this image to explain the light use efficiency of photosynthetic cells during the conversion of solar energy into lipids. The image is entitled "Improving photosynthesis for algal biofuels: Toward a green revolution."

To obtain an adequate amount of lipids at the end of the photosynthetic process, Stephenson and his co-workers claim that the processes of solar energy capture needs to be optimized.[69] Further, energy losses such as unused wavelengths of light, heat and fluorescence, and carbohydrate storage need to be minimized.

There is ample literature in algal biofuels research on the question of how to improve algae's photosynthetic efficiency, or how to go beyond the limits of this organism's photosynthetic capacity (Kruse et al., 2005; Mussgnug et al., 2007; Simionato et al., 2013). For example, Mussgnug and his colleagues (2007) propose to genetically engineer photosynthetic

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[69] Triacylglycerides, also known as "*[t]riacylglycerols* are particular forms of lipids with highly concentrated stores of metabolic energy" (Berg, Tymoczko, & Stryer, 2002).

light capture molecules and create mutants that can absorb more light by targeting particular properties of cells, as well as processes during photosynthesis. This work builds on the idea that green algae "evolved genetic strategies" that "maximize light capture under low-light conditions" (Mussgnug et al., 2007: 802). These green algae are similar to Mira's experimental cultures that were adapted to live under low light conditions.

In Mira's experiment, the question was whether specific low-light cultures can tolerate high-light conditions. In Mussgnug and others' studies, an evolutionary question becomes one of economics. The consideration is that low-light cultures are inefficient for obtaining biomass since they cannot absorb high solar irradiance. Thus, while large, light harvesting antenna complexes allow green algae to "grow slowly and endure," in Chisholm's words, they become limitations in the hands of algal biofuels researchers who try to obtain sufficient biomass at short notice. Algal biofuels researchers evaluate how algae's potential to photosynthesize, grow, and reproduce under low-light conditions—a capacity gained through evolution—sets limits on algal productivity. This means that they cannot obtain the biomass required to drive cost-effective bioenergy economies. Through this evaluation, researchers think that algae need to be potentiated as a technology to utilize "excess light energy" and, makes more energy that can be captured for human use. To overcome the limits of the strategies that algae evolved, algal biofuels researchers manipulate algal cells' targeted properties or processes. They work towards increasing the productivity of algae as a form of aggregate life, by accumulating maximal amounts of algal biomass. Yet, such genetic manipulations do not necessarily need to be targeted; they can also be generated randomly and screened, as in Halil Kavaklı's research.[70]

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[70] During our conversation, Kavaklı drew attention to the fact that "99 percent of mutations are fatal." Beginning with the one percent of mutation processes, his research team experimented with creating mutants with high lipid contents.

Kavaklı began his experiments with this question: if we can speed up the evolutionary process, would we obtain cultures that grow fast and at the same time produce the lipids required in economically feasible amounts? Kavaklı's research team employed physical and chemical methods while randomly mutating different colonies of *Chlorella vulgaris*.[71] In his presentation, Kavaklı explained the results of their experiment: Lipid and biomass productivity of the mutant colony increased. In Kavaklı's hands, algae are manipulated and rendered into new forms of life with high productivity rates.

During Kavaklı's presentation, I was drawn to his characterization of algal cells as "biocatalysts"—as things that activate the conversion of sunlight into organic compounds. The metaphor of algal cells as biocatalysts rearranges our ideas about algae as labouring organisms: algae now play a role in the manufacturing process of high-value added products in addition to lipids. Thus, researchers engineer algae to make them produce a range of materials for bioenergy economies. This metaphor not only signals an engineering approach to algal cells, but also suggests that if algae's photosynthetic potential is not efficient enough for bioenergy economies, that even this potential can be discarded in favor of something more productive. The company Solazyme, for example, adopts this idea, and uses algal strains that can grow in the dark. I will conclude this chapter with an exploration of Solazyme's project to determine how it challenges our notions of algal potentiation and what kind of a world-making processes it sets in motion.

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[71] Kavaklı suggests the problem with *Chlorella vulgaris* is that its genome is unmapped. This is because it was not *Chlorella vulgaris*, but another species, *Chlamydomonas reinhardtii*, that served as a model organism in genetic studies. Genetic studies of *Chlamydomonas* have provided detailed understandings of photosynthetic processes (Zallen, 1993b). Its genome (Merchant et al., 2007), its metabolome (Timmins et al., 2009), and its transcriptome (Nguyen et al., 2008) have all been "successfully" mapped (Zhang et al., 2015: 2025). Kavaklı also explained why his research team had selected random mutations: "It does not require the wealth of biochemical and genetic information on the organism at stake and requires minimum technical manipulation."

Coda: From Potential to Potentiation

What Makes Our Microalgae Unique[72]

> Microalgae are the world's original oil producers and the ancestors from which all plants have descended. After screening more than ten thousand microalgae strains, Solazyme researchers isolated a few truly unique strains on which we based our technology. Our main oil-producing microalgae strain, which is the basis for most of our products, was originally discovered over a century ago on the sap of a chestnut tree in Germany. It is naturally white, lives off of a wide variety of plant sugars and can grow without any light. Unlike many microalgae that commonly grow in ponds and rely on sunlight to grow, Solazyme's microalgae can natively convert sugars directly into oils and other whole algal products in closed fermentation tanks, offering a highly efficient, consistent and contained production environment.

In the above quote, Solazyme, one of the few companies producing algal biofuels in the United States, challenges our idea about algae as photosynthetic organism. This company invested in a microalgae strain that can grow without light, that is, without photosynthesizing.

Solazyme explores ways to eliminate "the light component [of algae] entirely, growing algae nonphotosynthetically, [by] using a reduced carbon source" from other materials. Under these conditions, "algal biomass can accumulate more rapidly and reach higher densities, since they avoid issues with shading and have a readily available carbon source" (Hannon et al., 2010: 773-774). The company uses another plant's photosynthetic products as a source of reduced carbon.[73] Carbon sources, sugars, such as those obtained from sugarcane or corn, are added to the fermentation tank, which contains microalgal cultures. The algae are fed sugars in order to maximize their production of oil. Thus, the economic potential of algae no longer depends on this organism's photosynthetic potential, but the efficiency of algae's conversion of sugar into oil. Solazyme thus aim to potentiate algae as an "efficient, consistent and contained" energy resource that does not depend on light.

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[72] http://www.solazyme.com/innovation/

[73] In the video embedded in the company's website, the process is explained with the help of animations (ibid.).

As this chapter has shown, neither these stories nor experiments about photosynthesis are neutral; rather, they make and unmake worlds. In this chapter, I examined one story of this world-making, that is, the potentiation of algal photosynthesis in the making of bioenergy economies. I drew attention to the economization processes that are already underway in the life sciences, even before algae come to circulate in markets. I made visible the ways researchers render algae as labouring organisms and accumulated matter. This account offers one way that STS scholars might redirect attention to discourses and practices that economize life beyond market relations.

At the same time, researchers' efforts to push beyond algae's "limits to efficiency" as well as Solazyme's push for growing algae in the dark made me rethink how economies are shaped by the questions of energetics and efficiency. Thinking with Melinda Cooper (2008), this chapter shows that efforts to go beyond the "limits to efficiency" shape and are shaped by technoscientific world-makings. My aim has been to develop new analytics to understand the work involved in potentiating life in the form of continuously accumulating and efficiently growing sources of energy. The next chapter will add "integrated systems," to this initial discussion of built ecologies, in order to grapple with how algal lives become resources in larger scale projects.

Chapter III: Potentiating Sustainable Algal Biofuels through Integrated Systems

In the midst of an interview with NASA researcher Jonathan Trent (2011b), a reporter inquired: "Are you passionate about algae?" Trent laughed. Perhaps the question caught him off guard, considering the interview's subject matter. Over the course of their conversation, Trent had crafted a nuanced, carefully considered account of the Offshore Membrane Enclosures for Growing Algae (OMEGA) Project's (2009-2012) conceptual and technical details. In his story, Trent explained that the aim of the OMEGA project was to produce biofuel feedstock from algae cultivated offshore. Notably, the project relied on an integrated system linked to both wastewater treatment facilities and carbon-dioxide-intensive industries to achieve its goals. Trent replied:

> Well, I guess if you haven't noticed by now, I'm passionate about algae, I'm passionate about the oceans, I'm passionate about the environment and I'm passionate about finding a way forward for the growing population of human beings that is sensitive to the environment and responsible on a global scale. Above all, I'm passionate about finding a sustainable, carbon-neutral energy supply and I think algae can be part of that supply.

Several narrative threads emerge from Trent's response—notably, we learn about the affectivity of his involvement in algae's potentiation as well as algae's "potential" as a sustainable energy resource. As highlighted in the preceding chapter, an inquiry into these affectively-charged narratives about algae helps us understand what motivates the researchers working with these organisms. Furthermore, this chapter also argued that attention to these stories illuminates how algae themselves are rendered "visible, tangible, and workable" (see also Myers, 2015). I demonstrated how Penny Chisholm's passionate renderings of photosynthetic organisms in microbial-oceanic ecologies figured algae as energetically labouring bodies—ones that are response-able for the maintenance and sustainability of life on earth. Chisholm's passion shaped her own sense of responsibility. In her quest to better understand the complexities of ecological systems, Chisholm devoted herself to learning as much as possible about algae. It is this material-semiotic-affective form of knowledge-making and storytelling that potentiates, enacts, activates, and legitimizes some imaginations and materialities, to the exclusion of others (Barad, 1998, 2003, 2007; Haraway, 1988, 2013; Myers, 2015). To underscore this argument, I drew attention to how Chisholm's evolutionary narratives render the "stuff" of photosynthesis. Her stories about algae's role in global carbon cycles, her characterizations of photosynthetic organisms as "metabolic engineers," the transformation of photosynthesis into a "technology," and oceanic ecologies figured as "machinic closed systems," all inform how algae get potentiated in practitioners' hands.

Trent's passionate feelings for algae and oceans have also given him a sense of responsibility—however, in markedly different ways than Chisholm's articulation of her responsibility. Trent feels that he must solve the new energy demands of an ever-increasing human population, demands that can no longer be met by fossil fuels. His feelings of responsibility are conditioned and produced by Malthusian visions of life. Notably, they centre on the question of "resource scarcity" amidst unchecked population growth. I contrast Trent's and Chisholm's affectively charged stories to highlight the different economic logics that underpin their respective projects. In Trent's stories of algal lives, these organisms are *already* rendered as a resource. While both Trent and Chisholm's accounts instrumentalize algae, Trent's economic logic differs slightly from Chisholm's. If Chisolm functionalizes algae as labouring organisms for economically productive energetic ecologies, Trent figures them as a resource for economically productive biofuel markets. This distinction should not be read as a totalizing difference between algae's beings and doings or how they are rendered as labouring organisms and resources. Rather than indicate different potentiations of algal photosynthesis, my ethnographic account of these projects shows that these renderings are connected to one another, and that they each make the other possible. To unpack this claim, this chapter will follow researchers working on integrated algal biofuels projects and ask how they, too, potentiate algae as sustainable biofuels. Through an analysis of integrated systems thinking and experimental design practices, this chapter will explore how the sustainability of algal biofuels is potentiated. It asks: *How is sustainability imagined and made in and through integrated algal biofuels production systems?*

This chapter focuses on two different integrated algal biofuels projects to analyze researchers' practices and the stories they tell us. First, I follow Jonathan Trent's OMEGA project in the United States. Second, I examine a Turkish algal biofuels project developed by an environmental engineer, Göksel Demirer, at Middle East Technical University (METU) in Ankara, Turkey.[74] The juxtaposition of these projects led by two scientists working in distinct geo-political locations allows me to examine different epistemic, affective, and temporal conditions of possibility for integrative algal biofuels projects. In so doing, this chapter explores the creation of these conditions of possibility by looking at the ways in which Trent and Demirer present their projects.

Further, this chapter investigates how algae's potentiality materializes as a sustainable energy resource. It does so by examining the particularities of each project's experimental practices and specifically focuses on the materiality of "ecologies"—such as photobioreactors—built for these experiments. Through these *built ecologies*, I question how algae become potentiated as sustainable energy resources. By approaching these built ecologies as objects of study—namely, as integrated systems themselves—I develop a methodology that helps make visible the material-semiotic-temporal-affective renderings of algae as simultaneously energetic

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[74] Demirer's project, "Integrated nutrient removal, greenhouse gas mitigation and bio-fuel and bio-product generation by using microalgal and anaerobic microbial cultures" (2012-2015), was funded by the Scientific and Technological Research Council of Turkey (TÜBİTAK).

labouring beings and as sustainable energy sources. I will show how integrated systems thinking and design is shaped by sustainability imaginaries, and how, in the act of potentiating algae as an energy resource, sustainability itself get potentiated and materialized in the form algal biofuel technologies. This chapter shows how sustainability gets made.

This chapter aims to contribute to studies of materiality, including literature in the fields of science and technology studies, feminist technoscience, anthropology, and geography. I explore the epistemic, affective, and temporal conditions that make integrated algal biofuels production possible and through which algae emerge as potential sustainable energy sources. I build on STS analyses of "anticipatory regimes" to scrutinize the forms and effects of future-oriented promises of biotechnologies (Adams, Murphy, & Clarke, 2009). Geographers' and anthropologists' works on "waste" and "resources" also inform this chapter.[75] My contribution to these literatures is to focus on the design and engineering of "integrated systems" in order to understand how materials, knowledges, ideas, techniques, technologies, and affects converge in efforts to potentiate algae as sustainable biofuels. Overall, this chapter intends to examine integrated systems as world-making projects, what feminist technoscience scholar Donna Haraway might call "relational material-semiotic worldings" (Haraway, 2016). Following Haraway's assertion that, "[n]atures, cultures, subjects, and objects do not preexist their intertwined worldings," I argue that integrated systems are also in-the-making (ibid:13).

The origins and development of systems thinking have long constituted debates in the fields of history and philosophy of science and technology.[76] As an object of study, systems

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[75] For the geographers work, for example, see Gille, 2010; Gregson & Crang, 2010; Hetherington, 2004; Moore, 2012. For the sociology and anthropology of waste, see Hawkins and Muecke (eds.), 2002; Hird, 2012, 2013, 2015; O'Brien, 2007; Reno, 2015.

[76] For example, see Bijker, Hughes, Pinch, & Douglas, 2012; Galison, 1996; Haraway, 2006; Hayles, 1999; Hughes, 1993; Kay, 1997; Mirowski, 2002; Taylor, 1988.

thinking has profoundly influenced several fields, ranging from art, anthropology, and architecture to the history of technology, management, and life sciences. Noting how deeply embedded this form of thinking has become, art critic Jack Burnham (1968) tells us that "[w]e are now in transition from an object-oriented to a systems-oriented culture. Here change emanates not from things but from the ways things are done" (in Shanken, 2015: 6).

The concept of the "system" is ancient; it has long been used in the sciences to explain how parts interact with one another to generate the "behavior of the whole" (Golley, 1996: 32-33). In philosophy, the concept can be traced back to Heraclitus and Greek philosophical ideas on "universal flux" and "the unity of all things" (ibid: 33). Between the two World Wars, the concept of a "system" was developed first as a field of inquiry before transforming into a science. From the 1950s until the end of the 1970s, systems thinking developed into a dominant mode of thought that spread from the sciences into daily life. Operational games, like Model Cities—which were "played for purposes of teaching and research"—brought systems theory to a lay audience (Light, 2008: 373). So, what is a systems approach?

One approach to systems thinking has been theorized by operations researchers, systems engineers, and managers as the effort to "manage diversity and scale of information and technology" (Johnson, 1997: 892). Although some concepts, such as game theory, information theory, and feedback control theory, were precursors to a systems approach, they emerged out of the 1950s aerospace industry and eventually these theories were brought together (ibid: 892, 893). MIT's Radiation Laboratory (the Rad Lab) played significant role in the story of the development of systems theory. The Rad Lab, in particular, was established and functioned during World War II for military purposes.[77] (Johnson, 1997: 900).

Mathematician Norbert Wiener and his colleagues at the Radiation Lab, control engineer Julian Bigelow and physiologist Arturo Rosenblueth, authored an article on anti-aircraft systems, entitled "Behavior, Purpose, and Teleology" (1943). The paper posited that, "systems could be studied in terms of their relationship to the environment" (Robles-Anderson & Liboiron, 2016: 252). This claim constituted the basis of cybernetics, a term coined by Wiener and his colleagues in 1947 during the Macy conferences (1946-1953). It originated from the Greek word *kybernetes*, which meant to "[govern] in the sense of 'steersman'" (Pickering, 2010: 3). It should be noted that cybernetics theory popularized "the perspective that complex systems can be treated as self-regulating feedback systems" (Taylor, 2005: 57).

The legacy of cybernetics is manifold in the sense that is about the art of control, as well as an intellectual pursuit. For example, in STS literature, cybernetics has informed thinking on the question of reflexivity and transdisciplinary research, the analysis of large-technological systems, as well as actor network theory. I argue that STS scholarship that treats "systems thinking" as an analytic or object of inquiry has not drawn enough attention to, or emphasized, the concept of "integration." Integrated system thinking, as will be discussed in this chapter, is slightly different from "system integration," which became "a new standard for government-industry interaction" after World War II (Johnson, 1997: 901). Integration as it is approached here also differs from the notions of "coupling," which means "hooking systems together to constitute each other's environment" (Robles-Anderson & Liboiron, 2016: 254); from the

[77] The Radiation Laboratory was "so named to disguise the real research objective of the facility," "to deceive Germany": "In 1940, radiation work was considered to be the domain of the most theoretical physicists and of no practical application to military needs" (D. Douglas, 2010: 87,88, 100).

concept of “mangling,” which means “the reciprocal coupling of people and things… in a process” (Pickering, 2010: 24); and from feminist “cyborgs,” which subvert command and control (Haraway, 2006, 2013).[78] The juxtaposition of Demirer and Trent’s integrated systems approaches in this chapter explores “integration” understood as that which is “combined into a whole,” or “united in one system” (*Oxford English Dictionary*).

This juxtaposition between different integrated systems teaches us new things about algae: we learn how algae become “integrated” discursively into bioenergy economies even as they are yet to be integrated in sustainable energy systems. It seems to me that the enactments of “integrated systems” fill a contemporary, *affective void*. My interlocutors’ embrace of integrated systems reminded me historian Leo Marx’s (2000) discussion on technology. Marx notes the shifting perception of “technology” from a field of study to an object of study in the 1930s. For him, this changing approach to technology was a response to articulate novel developments—large scale “amalgamation of science and technology,” e.g., the case of chemical and electrical industries reveal. He mentions about the “semantic void” that refers to “the lack of adequate name” to articulate what was changing (Marx, 2000: 563). When my interlocutors refer to integrated systems as the most effective sustainable solution to make industries clean, I imagine these systems as if they fill a void. I call it affective void to emphasize that they wholeheartedly embrace these systems.

In a world transfixed by the hazards of climate-change, there is a tendency to rely on technological fixes to remedy problems facing fossil fuel-based economies. The championing of

[78] The ways that cybernetics shape STS theories are diverse. While some, for example, Andrew Pickering and Bruno Latour adopt cybernetic visions in their work on troubling boundaries, whereas feminist technoscience scholars, such Donna Haraway and Lucy Suchman, question how cybernetic visions make some worlds possible to the exclusion of others. In other words, in feminist technoscience scholarship, cybernetics is employed ironically, as in the sense of Haraway’s cyborgs, to refuse the hegemony of certain world-making processes.

integrated systems can be read as a form of sustainability-in-action: the call for novel, sustainable energy systems is both a response towards a historically-shaped present devastated by ecological change, and an anticipation of sustainable futures that have yet to come. The notion of "integrated systems" thus fills the gap between anaesthetized forms of life facing apocalyptic futures, and forms of life activated to work towards hopeful futures. These forms of life are squeezed between different anticipatory futures in a still-unfolding present (Adams, Murphy, and Clarke, 2009). By building on the previous chapter's discussion of machinic renderings of algae, the following sections examine how integrated systems generate, embed, and constrain sustainability discourses and practices in their efforts to potentiate algal biofuels projects. What I argue is that sustainability is made through integrated systems.

To develop my argument, I base my analysis mainly on fieldwork conducted in Demirer's laboratory in the fall of 2014, as well as on web-based archival research on the OMEGA project that was conducted between 2013 and 2016. In order to develop my analysis of Trent's and Demirer's projects, I draw on interviewing techniques, document analysis, and participant observation, as well as a material-semiotic analysis of scientific articles, power point presentations, project proposals, reports, newspaper articles, and videos. I attend to the ways practitioners talk about and design their projects; the metaphors, concepts, knowledges, materials, techniques, technologies they use and build.

In the first section of this chapter, I examine the imaginaries of excess and endurance mobilized in Trent and Demirer's narratives. I do this through meta-level analysis of epistemic, affective and temporal conditions of possibility. By focusing on Demirer's work on integrated projects that aim to bring waste management and biofuel production together, I will draw attention to the ways that he figures "excess" in his stories about integrated systems. I will show

how discourses of excess—including imaginaries about the excessive abundance of sunlight or carbon dioxide—creates the conditions of possibility for integrating “externalities” (e.g. carbon emissions or waste) into production systems. What I show is that this integration bypasses externalities by treating them as environmental problems that can be solved. When I take into consideration that integrated algal biofuels system depend on these externalities, it seems to me that these externalities “need to remain external”—to be produced again and again—for algal systems working. Stated differently, algal systems are promoted and legitimized by the way of “fixing” these externalities, these systems are potentiated by the promise of solving environmental problems.

Further, in this section, I will examine Trent’s project to show how stories of integrated systems potentiate algae at specific temporal scales and with particular affective charge. I will show how imaginaries of present ecological conditions combine anachronistic narrations of algae as “enduring organisms,” and create visions of algae as perpetual providers of energy. I argue that these renderings of algae make then readily available resources for bioenergy economies. Further, I will use discourse analysis to unpack Trent’s talk of algae as a resource to underline how he reproduces both hype-laden and apocalyptic stories of the so-called “Anthropocene.”

The second section shifts its attention towards laboratory practices. There I focus on how experiments are designed and conducted to optimize algal cultivation in wastewater, and the production of biogas via algal biomass. I trace the flows of elements, such nitrogen, phosphorus, and carbon dioxide, in between and through different kinds of ecologies. By drawing attention to these flows through experimental test tubes and photobioreactors, I will show the slippery ways that algae is imagined simultaneously as waste, as technology, as biomass, and as food. I claim that these distinct potentiations of algae are made possible through researchers’ selective renderings of algae as resource. My aim is to make visible the ways that researchers turn algae into a sustainable resource. The chapter concludes by exploring how built ecologies not only diminish algal lives as exploitable resources, but they also shift our understandings of ecologies as systems.

Cultivating Interest in Algae

On a crisp autumn day in October 2014, I rode a bus from Istanbul to Ankara to visit Professor Göksel Demirer. I wanted to learn more about his recent project on algal biofuels. I was curious about why an environmental engineer would take on such a project. It had been almost twelve years since my last trip to Turkey's capital city. Reflecting back, the colour gray had dominated my memories of Ankara. In my mind, the city's somber hues mirrored a perpetually overcast sky, rimmed by drab government buildings. This vision of Ankara stayed with me for some time. It was only after hearing the memories of friends who lived and studied in Ankara, however, that the city took on another life. After several hours, I finally arrived in Kızılay Square[79] where I had to find a *dolmuş* (minibus) to the Middle East Technical University (METU). While trying to locate the right *dolmuş* among thirty or so identical vehicles, the bus stop suddenly blossomed into a riot of colours before me. Snapping into focus, the bus stop transformed into a veritable sea of green minibuses and pink government buildings, all framed by the verdant trees and lawns of Güvenpark. Individual faces in the crowd leapt out at me, their expressions reflecting jumbles of emotions ranging from hope to despair—all of this, I should note, was after the 2013 Gezi movement, before bombs exploded in the same square, and before the failed coup attempt in July 2016.

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[79] Kızılay Square is the popular name of one of the important urban centers in Ankara. After the 27 May 1960 coup d'état, it was officially named "Liberty Square" (*Hürriyet Meydanı*). Recently, following the failed coup attempt of 15 July 2016, the square was renamed 15 July Kızılay Democracy Square (*15 Temmuz Kızılay Demokrasi Meydanı*).

Eventually, I located my *dolmuş* and settled in for the long ride ahead. As the minibus finally pulled up the university entrance, I quickly gathered my belongings before passing through security. I handed over my driver's license in exchange for a visitor card, and asked the security staff for directions. I was told that I must take another minibus to the Environmental Engineering Department building. Refusing to spend another minute in a cramped *dolmuş,* I decided to explore the campus by foot instead. With over an hour's time until my meeting, I strolled through the grounds at a leisurely pace. Absorbing the scenery around me, I noted the unusual abundance of trees on campus. I later learned that university employees and students had planted these trees in the early 1960s—these woods, then, were the physical manifestation of generations of academics and students' protracted labour.[80] Marveling at this thought, I ambled on in self-reflection. Drawing closer to the historical *Devrim Stadı* (The Stadium of Revolution), several buildings sprang into view.[81]

Feeling fatigue setting in from my walk, I sat down on the grass in the area close to the stadium and gazed at one of the beautiful sculptures nearby (Image 2): two young people, a man and a woman, stand with raised and open arms, as if looking towards the future with determination and hope.

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[80] The interview with Prof. Inci Gökmen, an academic at METU (May, 7, 2015). The campus covers approximately 7,500 hectares; three quarters of it is forested.

[81] The stadium itself reflects the spirit of METU, as every year students write the word *Devrim* (Revolution) on its stands during the spring break festival. It is a political-symbolic act of remembering the student movements of the 1960s and 1970s: "This period was characterized by the widespread politicization of youth, particularly university students, who were increasingly divided into the two opposed camps of 'rightists' and 'leftists.'" (Neyzi, 2001).

Image 2 A Sculpture at the METU Campus
Photo from the google images.

I later learned that this sculpture is known colloquially as, “Yes, I got a C!” According to campus lore, it stands for engineering students who receive a C in their exams. That is the grade necessary to pass the class, thus the sculpture reflects the students’ joy and celebration. The sculpture stands for the challenging engineering education at METU, as interpreted by the students themselves. As I sat on the sun-warmed grass, I imagined that the sculpture could also represent the anticipatory, hopeful, promising futures of algal biofuels. Yet, when I reflected on METU engineering students’ interpretation of the sculpture as success mingled with hardship, I began questioning how hopes get shaped through different expectations.

The campus is also home to Lake Eymir; I like to think that this lake hosts the campus residents, rather than the other way around. Deep wells surrounding the lake provide fresh water for the entire campus. It is a site of leisure activities, from rowing and fishing, to cycling and picnicking, the lake and its surroundings provide a peaceful space away from the crowds.

Lake Eymir also has another purpose—it has also become the subject of scientific research on eutrophication. Eutrophication describes the process by which increasing levels of nutrients in a body of water lead to the overgrowth of algae (“algal bloom”), and the deterioration of water quality. In Demirer’s lab in the basement of the environmental engineering building, algae become a biological technology geared towards improving water quality. The threat of eutrophication in Lake Eymir, is transformed into an opportunity to cultivate algae for ecological restoration. The environmental engineering building is located where the built-up area of the campus ends and the forest begins. With the forests, the "C" statue, and the lake still fresh in my mind, I enter the environmental engineering building in search of Demirer's office. After a few moments of searching, I find the right door and give it a gentle rap.

Excess

Göksel Demirer was working in front of a large window, his back towards the open door. Hearing my knock, he got up, took a couple of steps forward as he greeted me in a kind and lively manner. I was impressed by the room's tranquil atmosphere. Outside, the canopy of nearby trees filtered streams of soft light into the room. In the background, I heard the gentle rhythms of classical music coming from Demirer's computer. I took my seat next to his desk and I introduced myself. His enthusiastic demeanor combined with the tranquil atmosphere was reassuring. I realized I had nothing to worry about. Eagerly, I asked my first question while placing my tape-recorder on his desk: "How did you begin working on algal biofuels?" Re-directing my question, he chided me, instructing me that, "It is first worth talking about what environmental engineers do." Noticing my confused expression, he continued:

> I mean, the role attributed to us. In the beginning of the 1970s, we [Turkey] were industrializing, growing, and thus producing waste. Given that someone had to deal with the waste, this discipline [environmental engineering] was established. Without questioning whether we can decrease the amount of waste and/or why we produce waste, the common understanding was: "Let's call the environmental engineers, and they can deal with it." Similar to the saying that, when there is a crime, call the police… I work more frequently on ways to prevent waste production… Of course, it is impossible to produce no waste at all, there will always be some amount of waste. So why can't we valorize this waste? [*Bu atığı değerlendirebilir miyiz?*]

Demirer told me that he had been working as an academic in the Department of Environmental Engineering at METU since 1997, in the same department where he received his BS and MS degrees. For his PhD studies, he studied at the Department of Civil and Environmental Engineering at Vanderbilt University in Tennessee. There, he developed expertise on anaerobic digestion processes, in which microorganisms break down organic matter and convert it into biogas in the absence of oxygen. When he began his job at METU, he established the anaerobic laboratory in the environmental engineering building's basement, where he continues to work to this day.[82]

As Demirer spoke, he questioned conventional ideas about environmental engineers as professionals who manage, or "fix," waste. He told me that he finds the questions of why waste emerges and/or whether it is possible to prevent waste generation to be critical to his work—he wanted to find what he calls "cleaner production." He challenged any "end-of-pipeline solutions" that approach pollution control by trying to overcome environmental problems after they arise. Cleaner production, for him, is not only a preventive strategy to decrease the possible risks of waste for the environment and human health, but also a way to re-use waste. Demirer thus developed all of his projects by following the "principle of waste valorization." In order to valorize waste, he draws on his expertise in anaerobic biotechnology.[83] Demirer explained at length the finer details of cleaner production and waste valorization. As he spoke, my mind drifted to the relation between waste valorization and algal biofuels. At first, I was lost. I couldn't see the connection. Where were algal biofuels in his story? Yet, as Demirer continued, I could begin to discern the relationship between wastes and fuels. Demirer had cultivated an interest in algal biofuels production systems because they could turn waste into new forms of value.

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[82] The fact that Demirer went to the United States for his post-graduate studies speaks to the transnational nature of scientific training in Turkey. One reason for going abroad for PhD studies is related to how high-ranked Turkish universities regularly employ scientists who received their degree from foreign universities, especially the ones in North America and the United Kingdom.

[83] Anaerobic biotechnology is "a cost-effective and sustainable means of treating waste and wastewater that couples the treatment process with the reclamation of useful by-products and renewable biofuels" (Khanal, 2008).

Demirer claimed that algal biofuels are a "win-win-win" opportunity. As he explained, "If the system gets designed and optimized successfully, the wastewater and flue gases can be used to produce algal biomass required for biofuels." For Demirer, algae not only provide energy resources in the form of biofuels, but also can treat wastewater and absorb carbon dioxide. I hear Demirer's slogan, "win-win-win" as an exclamation not just in the register of hype or hope, but also as an expression of how specific environmental "threats" can be translated into "opportunities." In this section, I will show how a discourse of waste as excess makes this translation possible.

During my fieldwork in Turkey, almost all my interlocutors in the field of environmental engineering told me something curious. They explained how they began to see algae not only as an environmental threat, but also as a *source of opportunities*. They referred to eutrophication when they talked about "algae as a threat." Eutrophication derives from the Greek *eutrophos* and connotes "well nourished" (Campbell et al., 2009: 1227). It is an ecological and biological concept that examines the impact of rising levels of nutrients, especially nitrogen and phosphorus, in a body of water. These are elements that algae use to photosynthesize, grow, and reproduce. The more nutrient-loaded the water, the more algae grow in it. The rapid and visible overgrowth of algae creates "surface algal scum or weedy shoreline growths [that] often have pernicious effects on aquatic ecosystems." These are called "algal blooms" (Graham et al., 2009: 5-6). Eutrophication is a sign of algae's simultaneously destructive and productive forces. Further still, when environmental engineers like Demirer potentiate algae's productivity, we can see how algae are made into an environmental technology—in this case, as a remedial waste-water purifier to prevent environmental pollution.[84]

Demirer is not only interested in algae as a biological wastewater treatment technology. He also wants to employ algae as a carbon-capture technology and to accumulate algal biomass obtained through pollution mitigation processes.[85] By the time I first met with Demirer in October 2014, the project team had already completed about half of the TÜBİTAK-funded project. The project's aims were threefold: (1) to produce algal biofuels and bioproducts coupled with (2) nutrient removal and (3) greenhouse gas mitigation efforts. The team had already cultivated algal biomass by this time and was working towards biogas and fertilizer production processes. On that autumn afternoon, and in the following days, weeks and months, I heard stories of algal growth and observed researchers working with algal biomass in powder form to produce biogas and fertilizers. And I learned to listen for the stories and experimental practices that featured algae as a "win-win-win" opportunity.

As I began my fieldwork in Demirer's Lab, I asked for the overall plan of the TÜBİTAK project. Demirer kindly shared part of the project proposal with me. I scanned through the six-paragraph abstract, circling keywords as I read: nutrient removal and wastewater treatment plants; concern about global warming and biological CO_2 mitigation; renewable energy and microalgal biomass; microalgal cultures and diverse applications; integrated process configuration; and iron and steel-making industry. I wondered how these keywords came

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[84] Algal bioremediation is a prevention strategy to mitigate the devastating environmental effects of domestic and/or industrial wastewater by treating them before they are dumped into bodies of water such as oceans or lakes.

[85] In the early 2010s, one of Demirer's graduate students approached him to propose a research project on bioethanol production via cellulosic materials. He directed the student to develop a project on algal biofuels instead, taking into consideration the lack of the particular lab equipment required for the proposed project. The student subsequently wrote her MS thesis on integrated nutrient removal and biogas production, by using microalgal and anaerobic microbial cultures. Following this thesis project, Demirer initiated a new algal biofuels project that speaks to concerns about climate change and employs algae for purposes of carbon capture.

together in the way that they did, and, more broadly, how concerns about global warming and wastewater were translated into an algal biofuels project.

I did not find an answer to this question while observing researchers working in the laboratory. Frustrated, I stopped by Demirer's office early one the morning—almost two weeks after our initial conversation. I greeted him and inquired about the overall design of his project. Although Demirer was not expecting me that morning, he graciously took the time to discuss the project. He started by showing me several PowerPoint presentations. While Demirer was occupied with his computer, I glanced back at the trees outside. Their falling leaves reminded me that two weeks had already passed by, and that I had yet to see the forest for the trees. I was still not able to grasp how algae were made to produce energy in an integrated system that includes wastewater treatment as well as carbon-capture processes. In the laboratory, I was only *seeing* the production of biogas in test tubes. Perhaps Demirer recognized the worry reflected on my face and began discussing one particular slide on his computer screen (Figure 6):

> The red dashed-line divides the overall project in two processes. The first process aims to treat wastewater and flue gas via the use of algae, specifically chlorella vulgaris and "mixed culture." The second process is about producing biofuels and bio-products through algal biomass obtained at the end of the first process…A project that eliminates waste as well as produces energy may look like a joke: There surely is no such single technology. It is about bringing a couple of processes together.

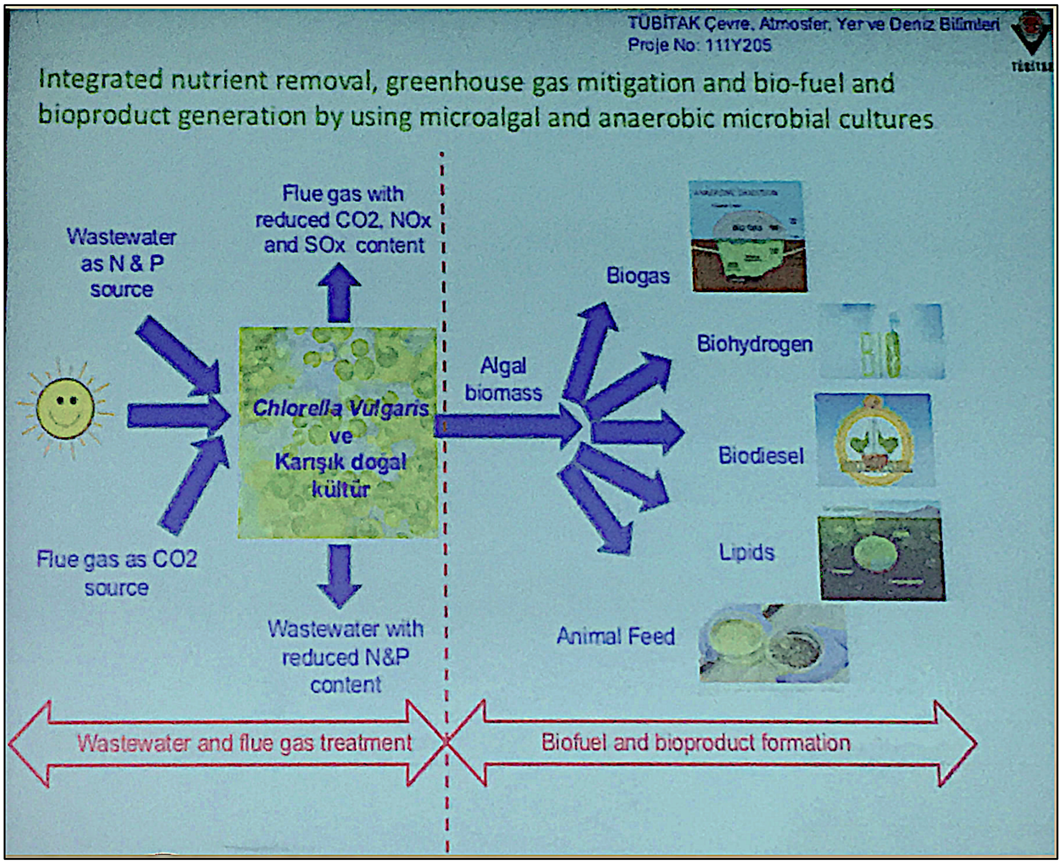

Figure 6 The Design of Demirer's Project.
Snapshot from a photo taken by the author during the presentation of Sibel Uludağ-Demirer at the seminar, "The water quality and environmental applications of microalgae," held at Boğaziçi University in Istanbul in May, 30 2016[86]

As the title of the project emphasizes, the above slide helped visualize how processes of wastewater and flue gas treatment are integrated inside of the making of biofuel and bioproducts. Separated by a red dashed line, the left side of the image depicts the arrows of wastewater, sun, and flue gas—each indicating the sources required for algae to photosynthesize and grow. The elements of nitrogen and phosphorus, which are considered as pollutants of water, are utilized as nutrition for algae. Carbon dioxide is the other element that algae necessitate to photosynthesize. Algal cultures reduce, if not totally remove, these sources of pollutants by absorbing them into

[86] The Turkish version of this slide is available through Demirer's publicly shared power point presentation documents on-line, see Demirer (2013, November).

their bodies. The outputs of the first process are: treated wastewater with nitrogen and phosphorus content is reduced; flue gases with reduced carbon dioxide, nitrogen oxides (NOx) and sulfur oxides (SOx); and algal biomass. The second process, “biofuel and bioproduct formation”, aims to produce a variety of outputs, including biogas, biohydrogen, biodiesel, lipids, and animal feed, via algal biomass obtained at the end of the former process.

Demirer used this slide to show how waste management and waste valorization come together in an algal biofuels project. The integration of these different processes renders algae simultaneously in the form of a bioremediation technology and a resource. The question here is: how is this rendering of algae situated in the world beyond the abstract diagram located on Demirer’s computer screen? In other words, what is concrete about this rendering? Following anthropologist Kim Fortun (2014), I suggest that rendering algae both as a remediation technology and as resource is in line with the familiar story that she calls “a modernist mess” in “late industrialism.” For Fortun, “late industrialism” is the timescale of “[d]eteriorating industrial infrastructure, landscapes dotted with toxic waste ponds, climate instability, incredible imbrication of commercial interest in knowledge production, in legal decisions, in governance at all scales” (Fortun, 2014: 310). In a conversation with Bruno Latour (1993), Fortun noted:

> Industrial order… in some of its dimensions, has indeed never been modern, mastered, subjected to law. Yet it is also modern with a concreteness that has had devastating environmental effects. It is these discontinuties that we must attend to… [E]ven if we have never been modern, we still have a modernist mess on our hands, a concrete mess, produced (in part) by what could be called an industrial theory of meaning and value, an industrial language ideology (Fortun, 2014: 310, 312) .

To Demirer, wastewater and flue gases are a “modernist mess” that need remediation. Fortun draws attention to particular forms of “remediation” that move such messes to other “more marginal places, out of sight and mind,” such is the case of environmental racism in the story she tells about Perry, Alabama, which is home mostly to African-Americans living below the poverty line (Fortun, 2014: 310). In Demirer's story, however, pollution is not externalized in this way. Rather, he tries to integrate, if not internalize, waste into "late industrialism."

Demirer's approach differs slightly from the efforts of environmental economists who treat "negative externalities," like pollution, as commodities to be included in the market (Scoones, 1999: 486). This line of capitalist thinking suggests the "cure" for pollution lies "within the market functioning of the system itself" (Swyngedouw, 2010: 223). Although Demirer's story appears to unfold along similar lines, I see his approach as more nuanced. Demirer is not merely reiterating another story of commodification—for example, as in the case of carbon trade. In that approach, externalities remain external, only to be integrated into the industrial order so as to create new markets and economic values.[87] Said differently, Demirer's project design suggests that if there are no externalities—such as excessive sources of carbon dioxide—it would not be possible to cultivate algae as biomass to drive bioenergy economies. In what follows, I demonstrate how visions of excess waste make possible the integration of externalities in algal biofuels production systems.

This vision of excess was first made clear to me when Demirer differentiated his work from other biofuels research that approached algae as an energy crop. Demirer did not devote his labour to manipulating and developing algal growing fast strains that could accumulate more energy. Rather, he explained:

> Actually, I do not want to say that it is meaningless to produce energy via algae. I don't know, it is just not my area of studies. I am not a person working on energy (*enerjici değilim*). But think about this: when you are doing something with a different aim, a *thing* [energy] emerges as excess on the side, and this is meaningful. What we try to do here is considering these two [energy production and wastewater treatment] together.

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[87] Although carbon dioxide was bought from an iron-steel industry in a commodity form within the scope of Demirer's project, it does not need to be always the case. For example, the project team got wastewater from a municipality not in exchange of money. Whether in the commodity form or not, what I emphasize here is that integrated algal biofuels production systems depend on this carbon dioxide in the form of pollutants.

In his account, Demirer gestured towards a particular literature on algal biofuels, which suggests cultivating algae in wastewater as a cost-saving and energy-efficient process. The idea is that using wastewater decreases the amount of fresh water requirements for algal cultivation to a great extent, while it also increases nutrients, especially phosphorus and nitrogen, that microalgae need to grow (Sialve, Bernet, & Bernard, 2009; Wang et al., 2010; Yang et al., 2011). Demirer did not propose using wastewater just to make the cultivation process more "efficient" and "economic." Rather, his initial aim was not to produce energy, but to remediate wastewater. Energy is a *thing* that emerges out of the wastewater treatment process. It emerges as excess—excess that is not wasted, but instead harnessed as added-value to industrial wastewater treatment systems.

As an environmental engineer, Demirer also differentiated himself from biologists. He acknowledged the importance and necessity of biological research on algal photosynthesis, but did not think that the lack of knowledge on algal biology constitutes an obstacle to his work on algal biofuels.[88] He works not *on*, but *with* algae. "I am not a biologist, but an engineer, a person who knows about everything as required," he stated, before continuing:

> As you know, there is something called photosynthesis. We learn about it in high school... Algae require sunlight, carbon dioxide, and nutrients such as phosphorus and nitrogen to grow. These are the three resources. Sunlight is *abundant*. The emission of flue gas by a factory produces maybe 1,000 times *more* carbon dioxide than is in the air we breathe. And this carbon dioxide is a waste that needs to be managed. Nitrogen and phosphorus, as pollutants, exist *in greater amounts* in industrial wastewater than in domestic wastewater (emphasis is mine).

Although Demirer did not use the term "excess," his invocations of "abundance," "more," and "greater amounts" insinuated a superfluous state. These are synonymous terms connoting a

[88] Demirer's engagement with photosynthesis surely goes beyond high-school level knowledge. He underlined many times during our conversation that having expertise on the topic about which one is working is critical not to "make the tools non-functional." The way in which he superficially talked about photosynthesis is not a question of expertise or knowledge, but reflects his mechanical and functionalist approach. See Chapter Two for a critique of similar approaches.

sense of "quantity": it is "the state of exceeding or being in greater quantity or degree than is usual or necessary" and "the fact of exceeding something else in amount or degree" (*Oxford English Dictionary).* In Demirer's words, abundant sunlight can be read as a quantity of sunlight that exceeds what is necessary for algae to photosynthesize. Carbon dioxide in industrial flue gas is greater in quantity than carbon dioxide levels in normal air. And the amount of nitrogen and phosphorus in industrial wastewater exceeds domestic wastewater amounts.[89]

Beyond Demirer's story, the idea of abundant sunlight is perhaps one of the most common narratives in promoting renewables in the form of solar energy. Sunlight, in this regard, rather than being a "matter of fact," emerges as a "matter of concern" with the transition to a new energy system that is not run by fossil fuels (Latour, 2004). I suggest, then, that it is worth investigating the imaginary of excessive sunlight as a political economic concern. My suggestion differs from Bataille's (1991) approach to "excess energy" in his theory of the general economy, in which excess energy creates the "effervescence of life" (p. 10; cf. Yusoff, 2009). Bataille argues against approaching the economy from a vantage point that poses the problems "*in the first instance* by a deficiency of resources." To him, these problems are "posed *in the first instance* by an excess of resources if one starts from the *general* point of view" (emphasis is original, Bataille, 1991: 39). In other words, Bataille critiques a Malthusian understanding of resource scarcity, to claim that the problem is not about scarcity of resources, but their excessive character. Accordingly, he argues:

> There is generally no growth but only a luxurious squandering of energy in every form! The history of life on earth is mainly the effect of a wild exuberance; the dominant event is the development of luxury, the production of increasingly burdensome forms of life (p. 33) .

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[89] Although all of these references constitute the figure of excess in Demirer's story of integrated algal biofuel production systems, each asks for a careful analysis in order to refrain from a reductionist interpretation of industrial-economic conditions that create capitalist commodities.

Bataille's critique of *luxuries*, which underlines excess rather than limits of a "general economy", is problematic. It reduces the question of economy to practices such as consumption. My probing of "excessive resources" here is more in line with a Marxian critique of political economy. For example, I am concerned with energy-value theories that figure excessive sunlight energy as the first required input of economic systems (Farber, Costanza, & Wilson, 2002). There are other, similar approaches that attribute value directly to "natural resources"—for instance; the eighteenth-century Physiocrats read "excessive resources of nature" as a form of surplus value, as a gift of nature. For the Physiocrats, land—as a gift—constituted the wealth of nations. Interpreting Demirer's take on excessive sunlight in line with the Physiocrats would be an exaggeration; however, the idea of "nature's gifts" is resonant.[90]

Demirer's story suggests that excessive sunlight is a gift. This is one "part" of his vision of an "integrated system." In his account, sunlight is prefigured as an "input" that is combined with wastewater and carbon dioxide to produce algal biomass for the generation of capitalist commodities, such as biogas and fertilizer. Moreover, excessive sunlight gains *use value* when it is integrated with "pollution" in the form of excessive carbon dioxide, nitrogen, and phosphorous in an algal biomass cultivation system. Even further, one could note that *surplus value* is generated through algae's work in absorbing "excessive pollutants." This becomes possible in

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[90] In anthropology and STS, the gift (Mauss, 1954) has long been an object of inquiry for understanding capitalist accumulation (e.g., see Tsing, 2013; Waldby & Mitchell, 2006).

integrated algal biofuels productions systems, which are conditioned through discourses of excess.[91]

Demirer's design of an algal cultivation process that draws on the excesses of late industrialism suggests that environmental threats, such as algae, can be translated into *opportunities*. A similar vision of threat-turned-opportunity has been criticized, specifically in analyses of the ways that capitalism operates as a political economic system. For example, in the case of carbon trade, scholars have drawn critical attention to the commodification processes by which carbon dioxide is subject to trade as a way to "fix" climate change (e.g., Dalsgaard, 2013; Whitington, 2016). Accordingly, these critiques suggest that the "threat" of climate change legitimizes the creation of new markets and thus generates new economic "opportunities" without taking the required steps to decrease and prevent carbon emissions created by fossil-fuel-based industries. In other words, these critiques stress the historical, political, economic, and sociocultural conditions that created such threats are obscured behind a rubric of opportunities. My analysis of Demirer's account adds more to this critique, and echos what David Harvey (2007) has called "spatio-temporal fixes" to the "capital surplus problem":[92]

> The basic idea of the spatio-temporal fix is simple enough. Overaccumulation within a given territorial system means a condition of surpluses of labour (rising unemployment) and surpluses of capital (registered as a glut of commodities on the market that cannot be disposed of without a loss, as idle productive capacity, and/or as surpluses of money capital lacking outlets for productive and profitable investment). Such surpluses may be absorbed by: (a) temporal

[91] Although Marx's critique of surplus value cannot be directly translated to understand the imaginary of excess in Demirer's story, a Marxian approach helps us to see that the question of labour is embedded, though remains invisible, in the imaginary of excessive waste as resource. Karl Marx developed his theory of value against the Physiocrats's attribution of surplus value to so-called natural resources. According to Marx, surplus value derives from the "excess of labour time over the value of labour power" by means of the extension of working time either through long hours of work or working without breaks (absolute surplus value), and/or through the reduction of the value of labour power by improving the production of commodities, for example, by using better machinery (relative surplus value) (Heinrich, 2012). Demirer's discussion of carbon dioxide, nitrogen, and phosphorous as excess, however, differs from Marx's use of the notion of excess in explaining surplus value.

[92] Melinda Cooper (2008), indirectly hailing David Harvey, has claimed that biofuels have been an "escape route from many of the United States' most pressing economic problems" (p. 48). This is similar to what Harvey has underlined with the absorption of surpluses of labour and capital through spatio-temporal fixes.

> displacement through investment in long-term capital projects or social expenditures (such as education and research) that defer the re-entry of current excess capital values into circulation well into the future, (b) spatial displacements through opening up new markets, new production capacities and new resource, social and labour possibilities elsewhere, or (c) some combination of (a) and (b) (Harvey, 2007: 64) .

Following Harvey, Demirer's story is one of "fixing" environmental threats, which appear in the form of excess. In this sense, one could consider forms of excess derived from "overaccumulation." Therefore, Demirer's integrated algal biofuels production system design project works in two ways: (1) it displaces threats temporally as his experiments are an investment in a long-term experimental project; and (2) it displaces them spatially as algae gain (new) production capacity with the promise of new markets such as biofuels.

In this section, I have tried to demonstrate how excess gets materialized in stories like Demirer's, and, how this in turn, legitimizes claims for integrated algal biofuels projects as "win-win-win" opportunities. In Demirer's story, algae are potentiated as an energy resource and as excessive pollutants. Furthermore, this section intended to make visible how excess—whether in the form of energy emerging as side stream, or abundant sunlight, or carbon dioxide as waste, or nitrogen and phosphorus as pollutants—becomes valuable in the moment when it is integrated into a system of production. Thus, it is not only capitalism as a system, but the integrated systems approach that creates and refigures excess as resource from the scale of laboratories to macro-political economies.

The figure of excess, as it becomes visible in engineering narratives, such as Demirer's, constitutes the epistemic conditions in which algae get potentiated as labouring organisms that absorb carbon dioxide, remediate wastewater, and provide energy. Yet, algae's potentiated labour is obscured through these same narratives when algae are figured as a sustainable energy resource. In order to better understand how algae become "sustainable" resources in the hands of researchers, I now turn to American scientist Jonathan Trent's project to explore temporal and affective conditions of possibilities.

Endurance

In a 2013 interview, NASA researcher Jonathan Trent exclaimed, "[p]eople have lost faith in biofuels." Trent believed that algae could help with re-cultivating that "faith":

> Biofuels are my passion, but they have had rather a bad press [*sic*], from complaints about displacing food production to the inefficiency of soybeans and the carbon footprint of ethanol. Microalgae have a low profile but they deserve a much higher one, since the fossil oil we mine mostly comes from microalgae that lived in shallow seas millions of years ago—and they may be key to developing sustainable alternative fuels (Trent, 2012) .

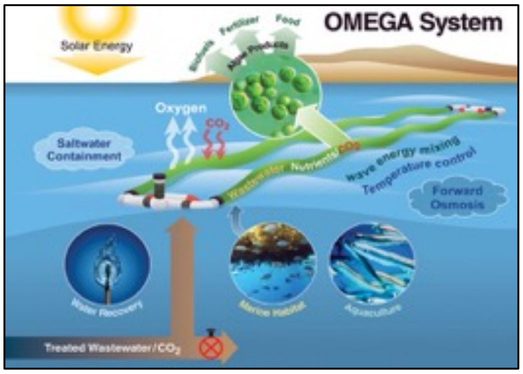
Trent signals the problems related to first-generation biofuels, lauding algae for providing solutions to these problems—problems that include the use of agricultural land for the cultivation of energy crops, and the inefficiency of crops such as soybeans on an industrial scale of production. For Trent dead and sedimented microalgae in the oceans constitute fossil fuels over time, and therefore living algae "may be key to developing sustainable alternative fuels." In other words, Trent suggests that the evolutionary timescale of algae is likely to solve problems on the industrial timescale of biofuels. Trent's reference to the evolutionary story of algae resonates with the evolutionary narratives discussed in the previous chapter, in particular, those narratives that naturalize algae's potential on the basis of its adaptation to various conditions throughout earth's history. In this section, I will examine algae, as enduring organisms, that is, as organisms that have endured the deep time of environmental change. I will explore how this idea of endurance is linked to ideas about the sustainability of large-scale algal biofuels production. I will demonstrate how the notion of endurance in Trent's narratives creates an evolutionary timescale that makes the potentiation of algae as a sustainable energy resource possible on an industrial-capitalist-economic scale.

Jonathan Trent developed an interest in marine science during his undergraduate years. After graduating, he decided to pursue his PhD degree in biological oceanography. Around the time when he completed his doctoral studies at the Scripps Institute of Oceanography (San Diego, California) in 1985, molecular genetic techniques were spreading widely. Trent followed this trend and undertook his post-doctoral studies on the biochemistry of extremophiles, the microorganisms that thrive in "extreme environments," at the Max Planck Institute for Biochemistry in Munich, Germany.

After leaving Europe for the United States, Trent first was employed at Argonne National Lab. There, he conducted research on extremophiles cleaning toxic wastes. In the late 1990s, right after NASA launched the astrobiology program, Trent began working at the Ames Research Center. During his work at this center, he cultivated an interest in nanotechnology. One of the projects that he focused on was improving the degradation of cellulose, and this drew his attention to biofuels:

> [T]here are two "holy grails" for biofuels, one is cellulose degradation and utilization and the other is microalgae. With my background in marine science, microalgae was [*sic*] a natural for me and I quickly dug into that literature (Trent, 2011b) .

As Trent mined the literature on biofuels, he confronted one of the biggest challenges in this field of study: how to produce biofuels on a large scale without competing with agriculture? With his background in marine science, a focus on microalgae came naturally to him. And at the same time, algae offered solutions to the problems inherent in first-generation biofuels—namely, the competition with agriculture in terms of food, water, and energy. Building on his areas of expertise, Trent would eventually launch a project that would become the hallmark of his career: the "Offshore Membrane of Enclosures for Growing Algae" (OMEGA).



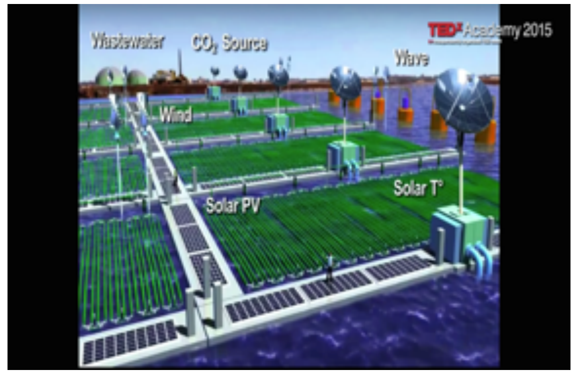


Figure 7 The Design of the OMEGA Project
The image on the left retrieved on-line. The image on the right captured from Trent's talk (TEDx, 2015)

The OMEGA system is an offshore system that cultivates algal biomass in floating plastic bags for manufacturing algal products such as biofuels, fertilizer, and food. Similar to Demirer's project, in the OMEGA system, algae are cultivated in the medium of wastewater fed by an additional carbon dioxide source. In addition to the waste treatment process, Trent's system also integrates local energy resources (wave, solar, and wind), as well as aquaculture. Overall, the floating platforms make use of wave energy and are covered with water-cooled solar panels, which produce heat and electricity required to pump and circulate nitrogen and phosphorus-rich wastewater within the plastic bags used as photobioreactors for algal growth. Below the surface, the system supports aquaculture for local seafood production.

According to Trent, oceans, and specifically, protected bays, are the best opportunities to establish cost-effective algal farms. He explained why: "some 40 to 60 percent of Earth's population lives near a coast, most of the biggest cities are near a coast, and nearly all coastal cities discharge wastewater offshore." Thus, bays are *potential* sites for the establishment of OMEGA Systems. Although there are no OMEGA systems yet in operation, the below figure shows research sites that are close to wastewater treatment plants and carbon dioxide-intensive industries, in particular American bays, such as San Francisco Bay and Monterey Bay.[93]

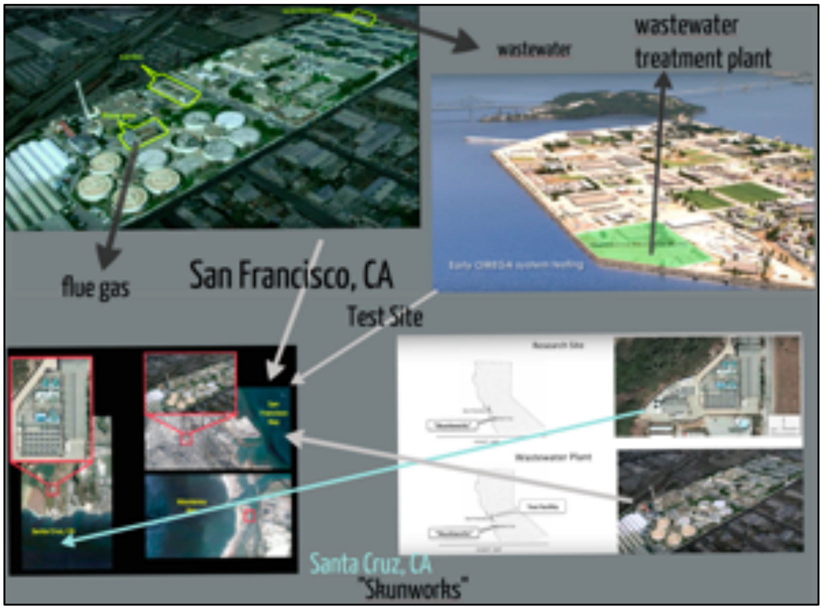


Figure 8 The research sites of the OMEGA Project
The image is designed by the author through the collection of images on-line.

Trent's offshore system for algal biofuels production draws on the idea of keeping the industrial system working continuously. In his view, for large-scale algal biofuels production systems to endure, economic issues first need to be taken into account. However, he sees opening the oceans to large-scale algal cultivation as an important step in avoiding competition with agriculture. Challenging algal biofuels projects that propose the use of "marginal lands" to build algal farms, Trent (2011b) has differentiated his offshore project by troubling the idea of marginal or non-arable lands:

> I don't buy the argument about using the so-called non-arable land for algae cultivation, because if we made all the effort of transporting water and fertilizer to non-arable land to grow algae, why would we not make it arable land and start growing food on it?

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[93] As the full name of OMEGA (Offshore Membrane of Enclosures for Growing Algae) already connotes, the political economics of this project constitutes a new form of enclosure extended from land to the oceans. Such an imaginary of enclosure not only limits the use value of oceans to specific power groups, but also establishes a (new) instrumental relation with nature (cf. Heidegger, 1977).

Trent challenges the claim that non-arable lands are only suitable for energy projects. Yet, Trent's critique is different from discussions about how the concept of "marginal land" works as an economic-technical legitimizing tool for land-grabbing, an issue that has been widely discussed in critiques of biofuels (e.g., see Nalepa & Bauer, 2012). In Trent's critique, economics override social and political concerns about marginalizing lands for re-appropriation, for example, for energy projects or construction. Trent's insistence on offshore systems instead of land-based ones is in line with what we learned about oceans from Penny Chisholm in the preceding chapter: that oceans are economically productive ecologies.

Yet, in Trent's account is distinct from Chisholm's story, in which ocean productivity hinges on the maintenance of "oxygen-carbon dioxide cycles." For Trent, oceans become productive when they allow large-scale algal biofuels production systems to endure. He is interested in the "economic sustainability" of these systems.[94] Trent's promotion of the OMEGA system as a solution to food, water, and energy problems thus needs further investigation. I argue that we need to unpack how the economic sustainability of the system gets translated into its ecological sustainability. One possible analytic could be to critique how Trent uses endurance as a concept.

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[94] Further, in line with her critique of geoengineering projects, Chisholm may argue against such offshore projects, considering them threating for the productivity of oceans.

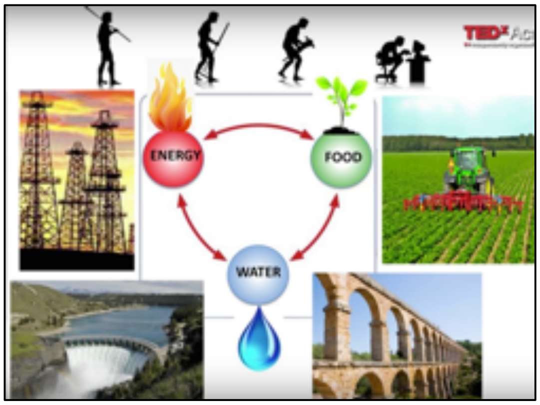

Figure 9 Energy-Water-Food Problem
Snapshot from Trent's talk (TEDx, 2015). It represents how Trent talks about energy, food and water as problems existed always, and humans responding to these problems by creativity in the evolutionary world history.

The image above is from Trent's recent TEDx Academy talk, entitled "Evolution in our environment from A to Ω" (2015).[95] It presents the problem of energy, food, and water as interrelated. In his talk, Trent located algal biofuels among pictures of other infrastructures designed to cultivate resources, while also providing a reading of history through popular imaginaries about the co-evolution of humans and tools. He reads tool evolution as "revolutionary," as responses to "what was going on":

> [T]he evolutionary process as you notice is really a question of an evolution of tools. The extensions of ourselves, the extensions of our hands, [and]…our ability to build. These were evolutionary, but they were also revolutionary. They were revolutionary because they were a gradual change that manifested at different times, because of the importance of what was going on…

Trent has claimed that humans developed tools to respond to problems related to energy, food and water. These tools are both evolutionary and revolutionary, as humans have the capacity to respond and provide solutions to these enduring interrelated problems. As he states in one of his articles, today, these problems come together and constitute the "big unresolved problems at which governments should be throwing funds and brainpower as if we were involved in a Manhattan Project" (Trent, 2012). Thus, the present energy-water-food problem, according to

[95] Trent J. (2015, October). Jonathan Trent - Evolution in our environment from A to Ω [video file].

Trent, should be tackled by a large-scale governmental program, and algal biofuels production should be a part of it.[96]

Trent's statement about the food-water-energy problem is neither naïve, nor arbitrary. It is a political and strategic act to lobby for his OMEGA project. It speaks to what some are calling the "popularization of 'nexus thinking' in policy and academic discourses" (Williams, Bouzarovski, & Swyngedouw, 2014: 4). "Nexus" emerged as a "powerful framework" in the 2000s to indicate "the complex interrelationships between water, energy, agriculture and climate," highlighting the relationships between different sectors, which had been previously considered separately (ibid: 5). The OMEGA system thus provides an example of a "nexus technology," a technical reconfiguration that draws together water, energy, and food (ibid: 6). The question here is how such integrated thinking about "problems" becomes possible in and through Trent's stories. I claim that the stories that figure these problems as enduring—as ahistorical but evolutionary—creates the conditions that potentiate and legitimize algal biofuels projects as "sustainable". This approach to food, water, and energy problems is resonant with a particular reading of history, one that Janet Roitman (2013) has explored in terms of "history *as* crisis" in her book *Anti-Crisis.*

Roitman has noted that, "crisis serves as the noun-formation of contemporary historical narrative" (Roitman, 2013: 2). In her terms, crisis is "taken to be a means to… think 'history' itself" (ibid: 3). For Roitman, the idea of crisis shapes how history is understood: it is history *as*

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[96] Trent, while claiming that the OMEGA system provides solutions to all these problems in an environmentally friendly and sustainable way, underlined how this system contributes to "green economies," what he sees as the "revolutionary tool" of present times. The concept of a "green economy," institutionalized in/through the United Nations Conference on Sustainable Development (Rio+20, 2012), has been subject to wide critical scrutiny for how it valorizes and monetizes nature conceived as "natural capital"; as if nature were a service-provider for human well-being (e.g., Escobar, 1996; ETC Group, 2011; Jessop, 2006; Kenis & Lievens, 2015; Shear, 2010). What I want to underline here is how ideas and practices around green economies are spreading in a way that legitimizes projects such as the OMEGA system.

enduring crisis. She asks whether one can "speak of a state of enduring crisis? Is this not an oxymoron?" (ibid: 2). Trent's vision of evolution *as* staging the enduring food-water-energy problem can also be seen as an oxymoron. Yet, as Roitman argues, such thoughts are not neutral, but political, as they undo "the possibility for other historical trajectories" (ibid: 11). In this regard, I argue that Trent's reading of evolution in relation to the imagination of history as problem-laden. History is as political as it is affective. It anaesthetizes "our bodies" by cultivating an "ecology of fear" (Davis, 1999) or "apocalyptic imaginaries" (Swyngedouw, 2010). It also activates "us" to take action and to find solutions to these problems.[97] In a 2014 talk, the affective charge of Trent's politics became much clearer.

In a panel held at Stanford University in 2014, Trent began his presentation entitled "Sustainable Energy for Spaceship Earth" after showing a video clip prepared for Rio+20.[98] In the clip, we hear a woman's voice, while seeing a number of segments from an image of planet Earth. The voice tells a story of how humans, as a species, have changed the planet:

> The latest chapter of our story begins in England 250 years ago. Fueled by coal and then oil… ignited the industrial revolution which spread like wildfire through Europe, North America, Japan then elsewhere. The great railways then cars and highways connected people across the globe. Medical discoveries saved millions of lives. New artificial fertilizers meant we could feed more people. Population grows rapidly. But this was nothing compared to what was to come. The 1950s marked the beginning of the great acceleration. Globalization, marketing, tourism and huge investments helped fueling enormous growth. People… in cities became more powerful engines of creativity. In a single lifetime, the well-being of millions has improved beyond measure. Health, wealth, security, longevity never have many had so much… In a single life time, we've grown into a phenomenal global force… Greenhouse gas levels this high have not been seen for over one million years. Temperatures are increasing. We have made a hole in the ozone layer. We are losing biodiversity… Sea level is rising. Ocean acidification is a real threat. We are altering earth's natural cycles. We have entered the Anthropocene, a new geological epoch dominated by humanity. This pressure on our planet risks unprecedented destabilization. But our creativity, energy and industry offer hope. We have shaped our past, we are shaping our present and, we can shape our future. You and I are part of this story. We are

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[97] To explore how dystopian and utopian, or anaesthetic and phantasmagorical imaginaries and narratives co-constitute one another, see, for example: (Buck-Morss, 2002).

[98] Trent, J. (2014, February). Franchise for humanity: Jonathan Trent on sustainable energy for spaceship earth [video file].

> the first generation to realize this new responsibility… We must find a safe operating space to humanity. For the sake of future generations.

The video ends with the slogan, "Welcome to the Anthropocene." And Trent, as if he had accepted the voice's invitation, began his talk. He raised the question: "Can we shape our future? I mean we're shaping our present, but can we shape our future?" By "we," he directly referred to the American people, not the wider "we as humanity" in the video presentation. Trent continued: "The US can now export another lifestyle to the world through the OMEGA." Thus, the OMEGA emerges as more than an algal biofuels project; rather, it is a way to "export a lifestyle" from the US to the world. Trent's way of welcoming the Anthropocene invokes an affectively charged temporality that reaches towards a capitalist, neocolonial vision of the future.

Trent's presentation speaks well to what Adams, Murphy, and Clarke (2009) have investigated through the notion of "anticipatory regimes": "The present is governed, at almost every scale, as if the future is what matters most" (p. 248). Accordingly, anticipation differs from speculation as it is more than gambling on the future. Rather, it constitutes a "moral economy in which the future sets the conditions of possibility for action in the present, in which the future is inhabited in the present" (Adams et al., 2009: 249). The conditions of possibility for such a moral economy is affectively charged and "manifest[ed] as entanglements of fear and hope," as in the narrative transmitted through the video (ibid.). Furthermore, in Trent's account, the anticipatory regime of the OMEGA project "tack[s] back and forth between the past, present, and future" through the figure of endurance, which makes transitions between different forms of sustainability possible, most notably, between economic and ecological sustainability (ibid:

256).[99] The OMEGA system continues to exist in its potentiality for "solving the problems of food-water-energy." It will continue to exist so long as anticipatory regimes need the continued existence of "hardship," "catastrophe," "problem," or "crisis."

The sustainability of large-scale algal biofuels production systems is not only about economics. Trent's stories inside and around the design of the OMEGA project embeds, implants, constrains, concretizes ecological sustainability in one way, while not permitting other forms to coexist. For example, consider local renewable energy forms, such as wind and solar, which are integrated into algal biomass cultivation systems. One could note that this integration makes the cultivation system ecologically sustainable. What concerns me is how sustainability imaginaries are constrained again and again in similar projects primarily through the logic of economics. Furthermore, these constrained sustainability imaginaries are not merely forms of "green washing," they are above all world-making projects. In the case of the OMEGA project, ocean grabbing replaces land grabbing.

The first section of this chapter aimed to make visible the epistemic, temporal, and affective conditions that potentiate integrated algal biofuels production systems. It showed how "excess" and "endurance" as figures of speech operate to potentiate these systems. In the second half of this chapter, I will explore the materiality of these systems as *built ecologies.* My aim in the following section is to show how sustainability is made in the form of algal biofuel systems.

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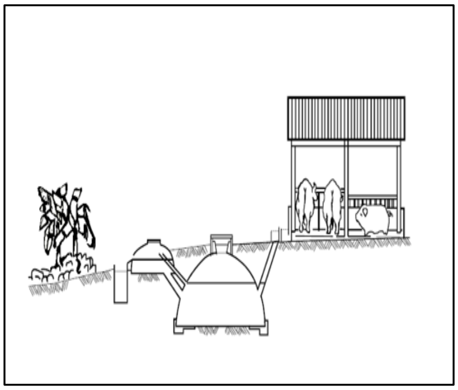
[99] In her book *Economies of Abandonment* (2011), anthropologist Elizabeth Povinelli explores social projects alternative to "late liberalism" and suggests "endurance" as a helpful concept for understanding the precarious existence of these social projects. Endurance in Povinelli's discussion connotes "the fact of enduring (pain, hardship, annoyance); the habit or power of enduring," and "patience"; it is "that which is endured; a hardship" (*Oxford English Dictionary*). Trent's account provides a different sense of endurance. In Trent's narrative, humans or (social) projects do not "endure" hardship by being patient; rather problems endure, and people act to overcome these problems by developing "tools," by being "creative."

Experimenting with Waste in Built Ecologies



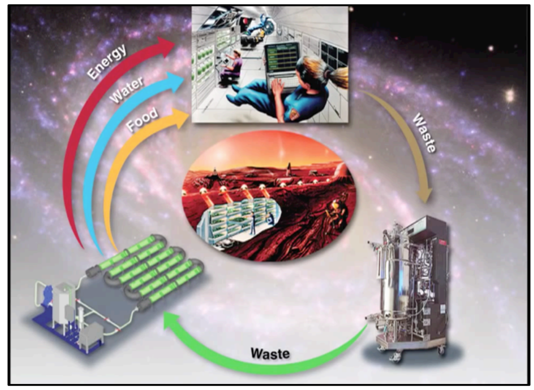


Figure 10 Re-cycling Waste
Images retrieved from on-line public sources. The image on the left is from Demirer's one of power point presentation; it represents installed biogas system near to an animal farm. The image in the right represents how Trent's OMEGA system is based on NASA's "life support system."

The above images reflect the main inspirations behind the algal biofuels projects developed by Göksel Demirer and Jonathan Trent. The image on the left is the drawing of a biogas production plant located on an animal farm. Demirer uses this image in his presentations about biogas production through organic waste. The image on the right is a representation of "life-support systems" developed by NASA. Trent uses this image in his presentations and articles to underline how waste gets recycled in space travel to optimize resource use. In this second half of this chapter, I will show how Trent and Demirer integrate "waste" into their experimental practices and how these choices, in turn, potentiate algae as sustainable energy resource. I will draw attention to the materiality of waste streams by focusing on the *built ecologies* these researchers have created in order to cultivate algae as biomass and render this biomass into biogas.

Social scientists, including anthropologists, sociologists, and geographers, have discussed not only what waste is, but also what multiple discourses and practices around waste in different societies teach us about people, cultures, economies, politics, and environments. I discern two main schools of thought in the literature on waste within the scope of this chapter. The first can be traced to anthropologist Mary Douglas's *Purity and Danger* ([1966] 2002). Douglas examined cross-cultural and temporal meanings of "pollution." Studies following Douglas's structural and symbolic account have explored waste as a "matter out of place," as well as a "mirror of culture" (Reno, 2014). By the 2000s, similar social constructivist approaches had been challenged extensively, and waste has become the topic of materiality studies (e.g., Gille, 2010; Reno, 2015).

The second school of thought treats waste as sociomaterials, and explores multiple underlying perceptions about waste and matter. For example, geographer Sarah A. Moore (2012) has mapped particular conceptualizations of waste, which include waste as hazard, resource, commodity, manageable and governable object, archive, disorder, filth, risk, fetish, abject, and actant. Further, scholars have approached waste as a lens to explore different issues, such as environmental politics, urban history, social behavior, social movements, capitalism, modernity, risk, regulation and governance (Moore, 2012: 780-781). Sociologist Zsuzsa Gille (2010) has also drawn attention to the deepening of theoretical and interpretive discussions in waste scholarship. Gille has divided these discussions into two strands: micro-level practices, such as practices of reuse, and theories on waste and society relations, for example, in terms of waste governance (Gille, 2010: 1049). In the light of this literature on waste in materiality studies, this section explores how the flow of particular elements in waste streams potentiates algae as sustainable energy resources. I offer a critique of integrated systems designs for algal biofuels in order to demonstrate how they shape and constrain sustainability through material re-arrangements.

The cultivation of algae in wastewater for bioenergy production requires nitrogen, phosphorus, and carbon dioxide. In high concentrations, these elements become pollutants—for example, when nitrogen and phosphorus accumulate beyond their " carrying capacity" in water, or when carbon dioxide accumulates in the atmosphere. As previously emphasized, these elements become resources at the moment they are integrated with algal cultivation, as algae require these to photosynthesize, grow and reproduce. Algal cultivation is undertaken in *built ecologies*, for example, in photobioreactors. In this section, I demonstrate how built ecologies work as elemental rearrangers (cf. Myers, 2016b). By doing so, I will underline some transitions between algae's different beings and doings: for example, how built ecologies render algae's ecological role in carbon-dioxide absorption as a technical matter, and how algal photosynthesis is transformed into a carbon storage technology. I argue that it is possible to see how algae, naturalized as labouring organisms, become resources through examining the moments of such transitions.

This approach to built ecologies not only makes visible the naturalization of algae's photosynthetic potential, it also helps make visible how discourses around waste are also shifting from inert materials to productive doings. In particular, I highlight how waste gains agency by examining Trent's design of the OMEGA photobioreactors. The following section thus examines how the elemental rearrangements that take shape within built ecologies embody, contain, and constrain ideas about sustainability. These discourses of sustainability selectively potentiate some of algae's beings and doings as well as shift perceptions of waste at the scale of industrial production.

Elements

> Algae require nutrients, light, water and carbon source, most often CO_2, for efficient growth. The major nutrients required by most algae include phosphorous, nitrogen, iron and sulfur. Often, the nutrient requirement necessary for algal growth is ignored, since algae are very efficient at sequestering these nutrients when present in their environment. Changes in nutrient load and algal growth have been studies [*sic*] extensively in terms of eutrophication of lakes and coastal regions, but not as heavily in terms of productivity in large-scale aquaculture. (Hannon et al., 2010: 766)

The above quote sheds light on three main phenomena that are part of scientific discussions about cultivating algal biomass in wastewater to produce biofuels: (1) eutrophication; (2) algal photosynthesis; and (3) large-scale systems. These phenomena are choreographed (Thompson, 2005) to potentiate algae as an energy resource. They render specific elements and waste flows into resources for algal growth. I ask: what makes this choreography possible? What does it teach us about algae's potentiation as a sustainable energy resource? This section will show how researchers *cultivate* algae in wastewater by rendering specific chemical elements into resources—I call these resources *potentiated materials.* I will show how harnessing waste through built ecologies turn algae into bioremediation technologies.

Eutrophication, as previously addressed, constitutes a significant reference point in the stories of algal biofuels researchers. In the above quote, Hannon et al. (2010) suggest that eutrophication can be a sign of algae as an opportunity. In this account, the notion of *productivity*, as it appears in the quote, not only makes the perception of a move from "threat to opportunity" possible, but also materially links the phenomenon of eutrophication to algal cultivation for biofuels. This is made possible through a particular approach to algal photosynthesis. Algal photosynthesis can take elements such as nitrogen and phosphorous, the very signs of eutrophication, and rearrange them to produce carbohydrates and oils. Thus, these pollutants can be used to build up algal biomass in built ecologies. I will substantiate this claim through the case of Demirer and Trent's experiments on algal cultivation in wastewater. Before doing so, I wish to emphasize that the interpretation of algal growth in terms of productivity is not specific to algal biofuels research, but also emerges at the very core of scientific definitions of eutrophication (see Campbell et al., 2009: G-14). These definitions suggest that the rising levels of nutrients in water increase the biological productivity of specific organisms, such as algae or cyanobacteria, while simultaneously decreasing biodiversity.

In line with these definitions, eutrophication becomes subject to pollution studies in the sense that the "[o]ver-enrichment of coastal waters by nutrients is considered a major pollution problem worldwide" (Glibert & Burkholder, 2006: 341). The overgrowth of algae, in the form of "algal blooms," shapes research projects that examine the relation between eutrophication and algal blooms, as well as the "harmfulness" or toxicity of the latter. An analysis of these pollution studies is beyond the scope of my research.[100] What interests me here, however, is how algae are transformed from a sign and signifier of pollution, toxicity or harm, to a technology that removes pollution. Demirer's and Trent's projects show that such a transformation is possible through efforts to cultivate algal biomass in wastewater.

"Wastewater has a great potential energy that we need to take into consideration," noted one algal biofuels researcher from Turkey at the conference entitled "Utilization of Microalgae in Wastewater Treatment and Environmental Applications" (Boğaziçi University, Istanbul, May 2016). He suggested a shift from energy-consuming to energy-producing systems. For him, algal cultivation in wastewater would make such a shift possible. His proposition brings to my mind Trent's TEDx talk (TEDx, 2015):

> The crux of the matter was food, we needed food, and we developed first the ability to make tools that helped us gather food, hunt food, and then, we started to cultivate food. Think of it. We grew animals, we grew crops. In fact, now we cover an area the size of South America with our agriculture. We cover the area of Africa with our animals, our livestock. We're a huge impact on the world, and we're cultivating; not just hunting and gathering, we're cultivating. This is about access and it's about storage. And water. Water is an incredibly important issue. Here, we're hunting and gathering. We're changing our storage by our industry. We're building huge dams, and we're moving water. We've moved water around the globe for a long time… And what about energy? All of this depends on energy. What are we doing for our energy?

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[100] For research on harmful algal blooms from an STS perspective, see Schrader, 2010, 2012.

> Mostly, hunting and gathering. Of course, we use hydropower, we use solar power, we use nuclear power. But mostly we're hunting and gathering fossil forms of energy.

In the above quote, Trent claims that humans need to become cultivators of energy, just as they cultivate food and water. For him, cultivation is about access to and storage of resources, mainly food, water, and energy, and thus maintains the sustainability of these resources. Algal cultivation is a form of aquaculture that is similar to agriculture, in the sense that algae are *cultivated.* Algae, like plants, are photosynthetic organisms and require nutrients, light, water, and carbon to reproduce and grow. The main nutrients that support algae photosynthesizes are phosphorous and nitrogen, and these are the major components of agricultural fertilizers. Imagine this: A farmer cultivates corn using fertilizers and irrigation. Fertilizers mixed with irrigation water enter the groundwater and make their way to the oceans. They become nutrients for microalgae, and these organisms grow while consuming these elements. If these fertilizers flow into the ocean at a rate that exceeds the "carrying capacity of ocean ecosystems," they cause algal blooms. If, however, the fertilizers, mixed with runoff irrigation water are collected via specially designed infrastructures, they become wastewater in which algae grow productively.

Thus, the main idea behind algal cultivation in wastewater is that the flows of phosphorous and nitrogen can be harnessed for algal biomass production, to access and store energy via algae photosynthesizes. As Demirer notes, wastewater can be from agricultural, domestic, or industrial sources; industrial wastewater is the most likely candidate due to the higher concentrations of phosphorous and nitrogen to support algal biomass production. For his TÜBİTAK-funded project, Demirer uses both domestic wastewater and wastewater from the iron and steel-making industry, and found that industrial wastewater was more productive for algae.

In short, the phosphorus and nitrogen contained in chemical fertilizers become pollutants in oceans and waterways. But they also can be figured as nutrients for cultivating algae in wastewater. Thus, these elements waver between waste, pollutant, nutrient, and resources, and this happens at the same time in different ecologies, and at different times in the same ecologies. The particular ecologies that interest me here are those *built* by scientists.

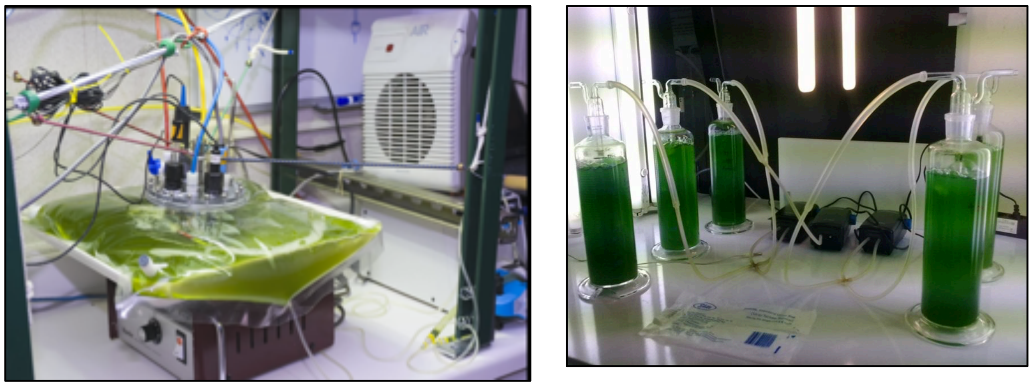

Image 3 Photobioreactors
The image on the left from on-line news page of NASA, from the article entitled “NASA envisions ‘clean energy’ from algae grown in waste water” (April 22, 2009). The image on the right is screenshot from Demirer’s presentation slides, available on-line (2013, November).

The above images show two different forms of photobioreactors (PBRs) to cultivate microalgae. The image on the left is from the experimental studies of Trent’s project. The image on the right is from Demirer’s anaerobic lab. They both contain wastewater fed by additional carbon dioxide as medium for algal growth. The algal strain that grows in these two reactors is *chlorella vulgaris*, a common algal strain known for its fast growth rates as well as its efficiency in removing nutrients and phosphorus in domestic, agricultural, and industrial wastewater.

The idea of cultivating algae in wastewater for biofuels development is not new. In the late 1950s, William Oswald and his colleagues at the University of California, Berkeley, proposed the use of high-rate algal ponds (HRAPs) to produce algae as biofuel feedstock in wastewater (Oswald & Golueke, 1960). HRAPs are “paddlewheel mixed, shallow, open channel raceways” and have been used at wastewater treatment plants in different parts of the world (Craggs, Lundquist, & Benemann, 2013: 153). These open ponds are inexpensive infrastructures to produce algal biomass. Yet, the problems of contamination and evaporation, as well as the lower yield associated with these ponds encourage algal researchers to work with PBRs.

The operation and management costs of PBRs are high in comparison to open ponds, as they require artificial light sources if built indoors, or additional systems such as cooling or heating, if built on land. To reduce these costs, the OMEGA project team developed floating PBRs located offshore. Trent (2011) has noted: "To produce biofuels, thousands of acres of raceways and tens of thousands of PBRs [located in deserts and unusable fallow land] will be required… The Devil is in the details." The details include how the PBRs are designed and installed offshore—as well as how they benefit from being located in the oceans.

The floating PBRs are made of flexible plastic bags with semi-permeable membranes. NASA has been testing these membranes, or selective barriers, for recycling dirty water in space travel. With the support of the NASA Aeronautics Research Mission Directorate and the California Energy Commission, the OMEGA team started their experimenting with small-scale PBRs in seawater tanks to measure algal growth in these PBRs filled with wastewater (Trent, 2011a).[101] The intent of this experiment was to measure algal growth rates in wastewater, as well as algae's efficiency in nutrient and trace element removal from wastewater. These measurements of algal growth rates and wastewater treatment capacities of algae are common to all experiments on algal growth in the medium of wastewater.[102] What was new in this experiment was the cleansing of wastewater—ideally without any added energy use—through

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[101] The OMEGA team is constituted of NASA scientists, navy engineers, civil engineers from the URS Corporation, and algal experts from the University of California, Santa Cruz. The facilities at the State Department of Fish and Game Lab (Santa Cruz, California) were home to this first experiment. In this experiment, the OMEGA team worked with floating PBRs that have a tubular design constructed of linear low-density polyethylene at the scale of 120 liters (Trent et al., 2012: 523).

[102] What scientists basically monitor in these experiments are photosynthetic efficiency, temperature, irradiance, dissolved oxygen (OD), pH levels and carbon utilization (Chapter Two).

osmosis.[103] The OMEGA teams' efforts to design a new form of PBRs illuminates why researchers build ecologies. They do this primarily to increase the efficiency and productivity of the cultivation system. The design of the OMEGA PBRs not only aims to increase algal growth rates, and also, to clean water for re-use.

By balancing osmotic pressures against hydrostatic pressure, the OMEGA PBRs benefit from the salinity difference between wastewater and seawater with the help of a selective semi-permeable membrane. As the figure below shows, the "water is pulled through the membrane by the salt gradient until the water on the right side [of the U-tube] balances the osmotic force pulling it through by hydrostatic force pushing it back." When wastewater and algae are put on the left side of the U-tube, the "salt gradient pulls only water through the membrane from the wastewater, leaving behind algae and wastewater contaminants."[104] The aim is to concentrate nutrients in the wastewater to stimulate algal growth (Trent, 2011a: 21). Further, this specific design of PBRs also benefits from the surrounding seawater for temperature control, which is a challenge in land-based PBRs (ibid.).

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[103] OMEGA-So, how does OMEGA clean the water? (2015)
[104] Ibid.

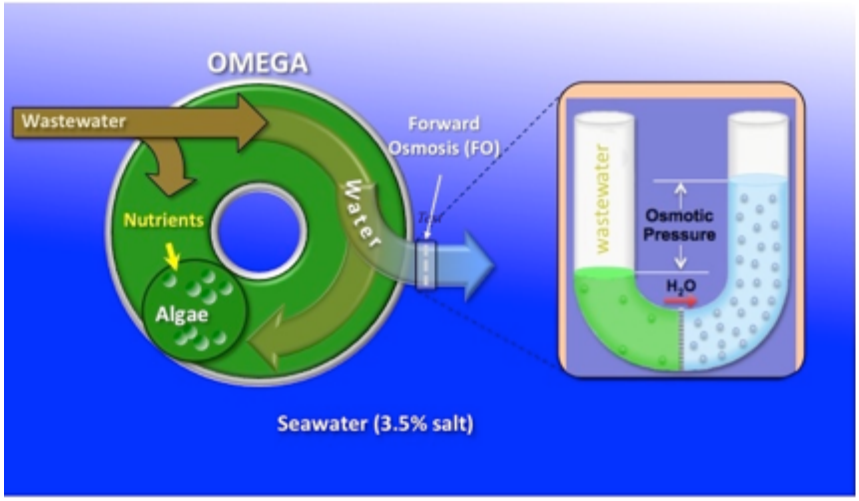

Figure 11 The OMEGA System
The image retrieved from the web-site of the OMEGA Global Initiative.[105] It explains the peculiarity of OMEGA photobioreactors, that is selective selective semi-permeable membrane. The image shows how forward osmosis helps algae growing as well as cleaning waste water.

The design of the OMEGA PBRs was inspired by NASA's "life support systems." The basic idea behind these systems is to re-use waste for "efficient" and "parsimonious" uses of resources during space travel. As Trent noted: "The challenging and rigorous space travel necessitates systems that optimize resource use" (Trent, 2011a: 22). He then suggested that the management of "limited resources" during long space exploration travel should also be a concern for life on planet earth, especially at this time of depleting fossil fuels, warming atmosphere, and increasing human population (Trent, 2013):

> In these life-support [systems], *waste is a verb* and everything we consider a waste product here on Earth is carefully scrutinized for its potential contribution to making food, clean water or energy (emphasis is mine) .

Trent talks about waste not as a thing, but as an agent. He sees waste as a catalyst, one that potentiates the making of food, energy, and clean water. In Trent's words, waste is not "matter out of place," as a Douglasian analysis would suggest. Rather, for him, "waste is a verb." Trent

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[105] Ibid.

imagines waste is an agent in stories that transform algal blooms and eutrophication into opportunities for water remediation.

Trent's idea of waste as a verb is made possible through built ecologies that rearrange elemental flows. Trent's approach is shaped by political and economic logics: it (1) reproduces Malthusian take on the scarcity of resources, (2) renders elements in waste streams into resources, and (3) creates sustainability as an outcome or effect, by rendering algae into a bioremediation technology.[106] In this section, I showed that the potentiation of algae as sustainable energy resource is made possible by harnessing "waste" via built ecologies. And that this depends on algae's consumption of waste. And yet, when I attended to experimental practices in Demirer's Lab, I came to see that algae are not only engaged as technologies, but also as food or nutrients in the process of potentiating algae as an energy resource. The following section will examine this point by focusing on a different kind of algal project.

Microorganisms

One day during my fieldwork at Demirer's anaerobic lab, Elif, a post-doctoral researcher working on the algal biofuels project, stepped into my temporary, shared office. The office was in the basement of the two-story building housing the Environmental Engineering Department, on the same floor as the lab. Elif let me know that she was ready to begin her experiment. She held two bioreactors in her hand. I hesitated for a moment. I thought to myself: was it better to spend a couple more minutes in a small claustrophobic room packed with desks, or in an experimental lab that smelled like shit? The office itself was already filled with odor, which was spreading from the hot room at the end of the L-shaped corridor. I decided to follow Elif as she

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[106] It is important to underline that algae have already been rendered into an epistemic thing at the scale of laboratory practices, before being potentiated as technical objects in and through engineered systems of production. For further discussion on how research produces epistemic things, see Rheinberger, 1997.

headed towards the lab. It felt like a sauna inside, the stifling air was thick with humidity. A couple of bioreactors were already busily humming away. I still had not been able to get used to the laboratory's odors. Other students going in and out of the laboratories and their office rooms did not seem concerned about the health effects of this malodorous air. Rather, they told me that they thought their immune systems got stronger from the exposure. Perhaps the students' testimonies about their immune systems, and perhaps the lack of signs showing the biosafety level of labs, helped to alleviate my worry over the possible health effects. In any case, olfactory adaptation made things easier for me over the following weeks.

The strong odor filling the corridors in the basement was the smell of methane gas, produced through the anaerobic microorganisms known as methanogens. Methanogens obtain their energy by using carbon dioxide to oxidize hydrogen and produce methane as a waste product in anoxic conditions. As part of their TÜBİTAK-funded project on algal biofuels, Elif tested the level of gas produced by these anaerobic organisms when they are fed algal biomass. She conducted the experiment with six bottle-type reactors, with a capacity of 50mL each. The bioreactors in this experiment were separated and labeled according to dry vs. wet algae, and mesophilic vs. thermophilic, alongside the control reactors. The terms mesophilic vs. thermophilic indicate different temperature rates.[107] Elif used wastewater sludge obtained from one of the wastewater treatment facilities in Ankara as the substrate for these reactors. She explained:

> To us, this sludge is biomass that contains anaerobic microorganisms… I add algae to it. In other words, I provide algae as food to these microorganisms… I assess biogas production against time. By biogas, I mean, I am looking at methane composition, hydrogen composition, carbon dioxide composition. These parameters are important for me, since there are a number of

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[107] While mesophilic connotes moderate temperatures, between 20 and 45 °C, thermophilic conditions are between 45 and 122 °C.

> gases that need to be produced in anaerobic environments. In short, I am looking at biogas potential.

To measure the "biogas potential" of anaerobic microorganisms fed by algae, Elif used a gas chromatograph (GC). As she was measuring, she followed the content and level of algal biogas on the computer screen, through a software program reflecting the measurements done by GC. Elif drew a specific amount of gas in a bottle-type reactor into a syringe and injected the sample into the GC machine through the injection port. As the sample gas flowed through the GC, the composition of sample gas was reflected on a graph on the computer screen. Elif explained how to read the graph:

> First, we see hydrogen, and then oxygen. There is no peak until 0.5 (minute). It means that we are lucky because there is no oxygen in the sample. The peak at 0.5 is nitrogen, and at 0.55 methane. We see carbon dioxide at 4.8... The measurement is done in two separate columns. The first column does not show CO_2. It means that this element does not get measured while the sample gas flows through this column in the GC. This first column is good for measuring hydrogen and oxygen. The second column is better for measuring methane concentration.

The GC helped Elif to see the gas composition in the sample as elements of hydrogen, oxygen, nitrogen, methane, and carbon dioxide gave electric signals while flowing through the columns in the machine, over a total of six minutes. In other words, GC-the-machine as an "inscription device" was transforming "matter [gas] between one state and another," while configuring matter into a diagram (Latour & Woolgar, 1986: 51). Yet, the experiments about algae's biogas potential conducted in the Demirer's Lab were not only inscriptive, they also *make matter come to matter* (Barad, 2013). The biogas obtained through the experiment *matters as a biofuel*, just as algae come to matter as food for the anaerobic digestion process. And, I learned that cultivated algal biomass does not constitute food by itself; rather, researchers must render algae edible.

Researchers employ several techniques to make algae more digestible for anaerobic microorganisms. The argument goes as follows: "The rigid cell wall structure of microalgae, which is resistant for microbial degradation," poses some limitations (Calicioglu & Demirer, 2016). To overcome such "limitations," Demirer's project also included experiments on pretreatment processes that utilize physical, chemical and biological methods.[108] I had a chance to follow up on the results of these pretreatment experiments almost a year after my fieldwork studies in Göksel Demirer's lab, during a seminar held at Boğaziçi University in Istanbul in (May, 30 2016). Sibel Uludağ-Demirer, another member of the TÜBİTAK-funded project led by Göksel Demirer, presented on the "biogas potential" of microalgal cultures subjected to pretreatment methods with reference to the methane production yield. Comparing the results of different pretreatment methods, she described how the autoclave treatment, increasing the heat of the built ecology constituted of algal biomass, resulted in the "highest performance." What Uludağ-Demirer referred to here with term "performance" is the performance of the anaerobic microorganisms' consumption of algal biomass—that is, anaerobic biodigestion (AD)—and the production of methane. She concluded her presentation by noting that, although the "AD of microalgae is a viable option for the recovery of bioenergy from wastewater by conversion of solar energy into chemical energy," the costs of pretreatment applications need to be taken into account.

Each *built ecology* potentiates algae in different ways. The experiments in Demirer's lab demonstrated that the bioenergetic efficiency of algae depends on the effective rendering of algae into food for anaerobic organisms. Thus, the potentiation of algae in built ecologies is always about the activation of different potentials. For example, in the scope of the OMEGA project, I explored how built ecologies render algae's photosynthetic capacity into biomass. Alternatively,

[108] These pretreatment methods played with the heat, pressure and pH sensitivities of ecologies built in reactors to increase the effectiveness of the anaerobic biodegradation of microalgae. For example, microalgal cultures were microwaved in autoclavable bottles at 121°C for 2 hours, or the pH level of the environment was increased with the application of another method.

in Demirer's lab, I learned about how built ecologies transform this biomass into a sustainable form of bioenergy.

In this part of the chapter, I developed the concept of "built ecologies" to address the *materialities* of algal technologies, as well as their roles in potentiating algae as a sustainable biofuel.[109] I examined experimental photobioreactors and bottle-like reactors as built ecologies to explore what goes into and comes out of them. I am particularly interested in their effects. I am intrigued by the ways that toxic flows—such as those of phosphorus and nitrogen—were revitalized and activated as nutrients through built ecologies. And in the case of producing biogas in reactors, how algae are potentiated and reactivated as food.

By drawing on ecology as a way of thinking, I approached these reactors not as simply containers, but as built ecologies.[110] In the process, I found that Demirer's and Trent's analyses are based on a systematic way of thinking that integrates different technologies and processes. For example, Trent talks about the OMEGA system as an "ecosystem of technologies," while Demirer similarly evaluates his algal biofuels project in relation to his works on "industrial ecosystems." What then, do Trent and Demirer mean by "ecosystem"? To conclude this chapter, I will show how the employment of ecosystem as an analogy conditions the design of integrated algal biofuels projects at the same time that it potentiates specific understandings of sustainability.

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[109] By "materialities of ecologies," I do not mean material studies of ecologies that attend to the flows of energies and materials to assess the "productivities" of ecologies.

[110] The ecological thinking that underlies Demirer and Trent's algae experiments is different from scholar Lorraine Code's (2006) Deleuzian take on ecology when she proposes ecology as a way of thinking. To Code, ecological thinking is the most radical turn in philosophy since Kant's human-centric Copernican Revolution. For her, ecological thinking is about "imagining, crafting, articulating, endeavoring to enact principles of ideal cohabitation" beyond the human (Code, 2006: 24).

Ecosystem

The concept of "ecosystem" is a floating signifier. Ecosystem as a term was invented by the English botanist Arthur Tansley (1871-1955) in 1935 and became "a guiding paradigm of ecological science" thanks to the American ecologist Howard T. Odum's research (Golley, 1996: 1). By the 1950s, the disciplinary focus in ecology shifted from gardens to ecosystems. Alongside it, the idea of rational management of "natural resources" shifted to a functionalist approach to nature (Kingsland, 2005). This transformation was in line with development of the Cold War, and thoroughly Americanized systems thinking (Golley, 1996: 2). Whereas ecosystem studies in Europe and Japan at that time were related more to "organismic theories" than to systems, engaging with information theory and using computers and modeling was an American affair (ibid.).[111]

This conceptualization of ecosystem in the United States is traceable to the Yale ecologist G. Evelyn Hutchinson's (1903-1991) claim that ecological relations are systems, contrasting them to approaches taken by advocates of organicism (Taylor, 2005: 53). Hutchinson worked towards a "practical program of ecology" that "integrate[s] biological and physical processes" (ibid: 56). In this regard, he introduced "biogeochemical" and "biodemographic" approaches to the field of ecology. His student, Odum, developed the biogeochemical approach, which became systems ecology—that is, ecosystem studies (ibid.). Odum, in reference to Alfred Lotka's works, suggested studying ecosystems as energy circuits. Thus, energy and matter, displaced by the rise of cybernetics in the physical sciences, found their home in ecosystems ecology, which quantitatively studies the flow of energy and matter through an ecosystem imagined as a large

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[111] "Organismal theorists point out that physiology offers ample evidence that the organisms functions as a fully integrated whole, and not as a collection of individual unities…[Organicists] maintain that the organism as a whole remains the true individual unit of life" (Nicholson, 2010: 206).

cycling entity. In Odum's studies, energy became the currency and the dominant mode of thought (ibid: 66). These energetics studies and ways of thinking in turn shaped Trent and Demirer's understandings of ecosystems as well.[112]

Trent's OMEGA system—an "ecosystem of technologies"—emerges as an energetic ecosystem, one that evaluated through the comparison between energy consumed for producing algal biofuels and the economics of algae as energy resource. Similarly, Demirer's experiments on algal biofuels intend to measure whether the energetics of biogas production via methanogens would increase by adding algal biomass into the system. In the second Chapter, I showed how the ideas about energetics shapes the ecosystem concept. Here, alongside Demirer's and Trent's project, I want to emphasize how this ecosystem approach also changes the way industrial production processes are conceived in contemporary times. One example is the promotions of "industrial ecosystems"—also known as "industrial ecology"—as a sustainability approach, which also shapes Demirer's work. The underlying idea of the industrial ecosystems approach is to "reduc[e] ecological impact[s] through increasing connectiveness of material, energy and information flows, actors beyond the regional level have sought to stimulate its practice" (Boons, Spekkink, & Mouzakitis, 2011: 907). The primary claim of this approach, then, is that an industrial system is a certain kind of ecosystem (Erkman, 2001). In this regard, industrial systems aim to mimic natural ecosystems. From this claim, the following argument emerges: similar to closed ecosystems in which nothing is wasted, collaborative and synergetic relations among industries are likely to provide optimal resource use as well as ways to increase resource

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[112] See Chapter Two for a further discussion on energetics.

efficiency.[113] What is significant here is that such analogical thinking becomes possible within the context of "sustainability," as Demirer explained to me with the help of a slide (Figure 12).

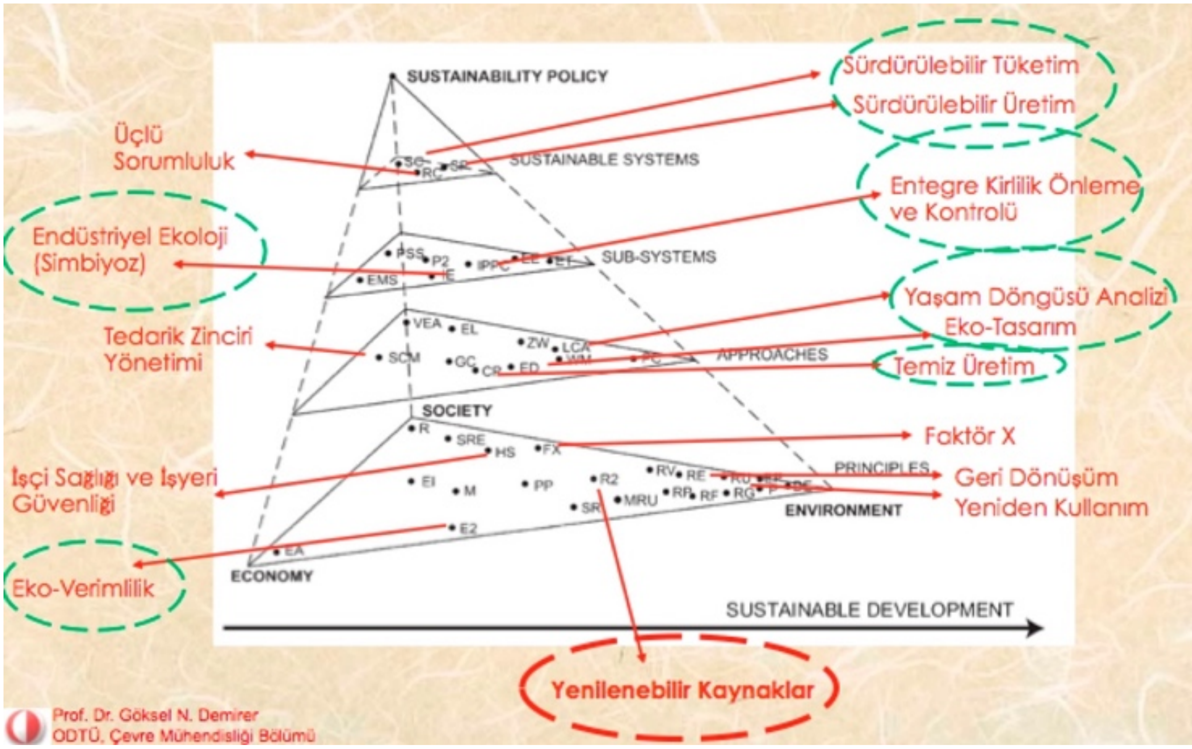

Figure 12 "Sustainability"
Snapshot from the slide retrieved from Demirer's power point presentation shared on-line, see Demirer (2013, November). As it is cited in the image, Demirer adopted the diagram from Glavič & Lukman, 2007.

The slide above is written in English and Turkish. The Turkish words explain what the dotted points signify. The prismatic drawing represents the relations between sustainability policy, economy, environment, and society, with regard to "sustainable development." From top to bottom, the layers read: sustainable systems, subsystems, approaches, and principles. Altogether they constitute sustainability policy, including different "tools" represented by the dots. The circled Turkish concepts are the field of studies in which Demirer is interested, as well as towards which he is working. "Sustainable Consumption and Sustainable Production" is about

[113] Although many consider industrial ecology an oxymoron, the idea of creating an ecosystem in the field of industry continues to inspire research (Huber, 2000).

sustainable systems. “Industrial Ecology (Symbiosis)” and “Integrated Pollution Control and Prevention” are sub-systems. While “Clean Production” stands as an approach, “Renewable Resources” is a principle.

Sustainability, in Demirer’s imagination as reflected in the above figure, does not stand as a buzzword, or an empty signifier. It is, rather, instrumentalized as a method to substantiate and legitimize his work (Escobar, 1996; McManus, 1996). Demirer works on cleaner production, industrial ecology, pollution prevention and control, as well as renewable energies, among other topics. For Demirer, these fields coalesce into a global project concerning “sustainable development.” In other words, sustainability as a method helps him to integrate his different projects which otherwise appear disparate, such as waste treatment and renewable energy. Yet, sustainability is in-the-making each time a scientist or an engineer, like Demirer, designs and engineers new projects. Put differently, sustainability is made in the hands of engineers like Demirer. It has been the contention of this chapter to demonstrate how integrated algal biofuels projects embed, contain, constrain as well as re-make sustainability. The question that remains is simple, yet complex: what kind of worlds are in-the-making in these integrated algal biofuels projects?

Conclusion: “Algae’s Potentials” Potentiated in the Same Way?

I see integrated systems thinking and design as world-making processes. This approach brings the historical debris of the 1950s Cold War era—replete its cybernetic and nuclear war sensibilities—into conversation with present desires for “sustainable” futures. This systems approach is one response to life downstream from the toxic flows, warming climate, and displaced peoples of late industrialism. Although Demirer’s and Trent’s projects remain at the experimental phase, I take seriously these designs as material-semiotic enactments that potentiate algae as a sustainable energy resource. I also see how these organisms and other life forms are made to matter as technologies and food. Put differently, I find it important to make visible the conditions of possibility that shape these projects, and to analyze their sustainability effects and affects so as to open new realms for alternative sustainability imaginaries. However, each project deserves careful analysis not to reduce them under the rubric of integrated systems of production.

Thus, I suggest this study of as yet unrealized technologies can help to unravel assumptions about biofuels projects. In the STS literature, such unrealized expectations are analyzed in relation to questions of hope, promise, hype, speculative futures, unknowns, or anticipatory regimes. These studies shed light on the temporal and affective dimensions of scientific projects and their epistemic as well as capitalist and colonial values. However, this literature does not yet speak to the question of difference in anticipatory regimes. The specific meaning of difference here can be illustrated by the sculpture on the METU campus, which I described at the very beginning of this chapter. My reading of the "C" sculpture diverged from the interpretation given by engineering students, and this difference pushes me to think that this not just a question of relativity, but rather of differences in the positionalities that frame expectations. Given that an environmental engineer's subject position differs from that of a NASA scientist, their expectations may differ too. My sense is that such distinctions in perception and expectations are not fully circumscribed by professions or regions, but also shaped by the ways that futures are imagined. This point was made clear to me in a conversation with Demirer, when he told me:

> There are two main schools of thought [*ekol*]. The first focuses only on system change. The other still keeps its emphasis on system change, but suggests building the future now so as not to miss the train.

Not to miss the train… The figure of the train suggests that we must work towards "sustainable futures" now, before the opportunity is gone. He notes that, without changing the system, by which he means capitalism, it is neither possible to prevent climate change, nor other problems associated with fossil-fuel-based economies. For Demirer, there is a train on the tracks, carrying possibilities forward towards sustainable futures. Thus, for him it is important to shoulder the responsibility to create “good models” now. Demirer aims to “develop these projects and throw them into the sea in the hope that someone will find them.” He does not attribute to algal biofuels a role that has the potential to change the contemporary energy system, as Trent imagines. Rather, Demirer attributes a progressive role to scientists who should develop good examples and disseminate them so as not to “miss the train.” His emphasis makes sense when we take into consideration the Turkish experience with modernization and biofuels, which I will turn to next in the following chapter.

Chapter IV: Untimely Timeliness of Algal Biofuels Research in Turkey

During our conversation on Turkey's biofuels policies, Mehmet, a biofuels scientist in Turkey, told me: "In rural areas, people still burn *tezek* [dried dung]." He asked, "How would you convince these people to produce algal biofuels?" Mehmet thinks that Turkey is still a developing nation and, thus, algal biofuels are not as viable here as they would be elsewhere in the world. During fieldwork, I encountered similar claims suggesting that Turkey is "not ready" for algal biofuels. These claims frame Turkey in particular ways: for example, they figure Turkey simultaneously as (1) an agrarian developing nation; (2) a country that lacks adequate legal, knowledge, and technological infrastructures to install algal biofuels; (3) a country where its biofuels sector is "premature"; and (4) as a country that is already too heavily invested in its fossil fuel resources.

However, in contrast to these common refrains and sentiments about Turkey, a number of my interlocutors working on biofuels, algae, and/or algae-related technologies emphasized that Turkey needs to "catch up" with the West—notably, in its renewable energy sector development. This desire to "catch up" with the West has been critical to Turkish politics (Akbulut & Adaman, 2013: 1).[114] Turkey is positioned as having the "potential" to develop its own algal biofuels projects. The country's geography is often referenced to make this claim: Turkey is bordered by the sea on three sides, it is located along the Mediterranean sun-belt, and thus has suitable environmental conditions for algal farming. Additionally, the Turkish scientists I worked with expressed their confidence that their technological expertise and knowledge of biofuels were mature enough to launch "advanced" algal biofuels projects. Finally, Turkey is regarded as an

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[114] I am aware of the constructed nature of the categories "West" and "East." Since my aim is not to develop a critique of the perceptions of world divided as such, I do not use quotation marks when I refer to the West—I keep it as the referential phenomenon, as used by my interlocutors.

"emerging economy," ready to invest in new energy infrastructures. These figurations of Turkey as "not being ready" and Turkey needing to "catch up" speak to different, yet simultaneously entangled perceptions about the country; they broadly situate algal biofuels projects within the terms of modernization.

The juxtaposition of these assessments—that Turkey is "not ready," and that it must "catch up"—illuminates the nation's experiences with modernization through development projects. From this vantage point, algal biofuels appear in the stories of Turkish scientists as a symbol—one that signals different perceptions about Turkey's development, either in economic or sociocultural terms.[115] When I listened closely to the different stories my Turkish interlocutors told me about algal biofuels, I realized that these sentiments both hinge on a vision of "Turkey's potential." These stories revealed to me that the rhetoric of "potential" cuts through these different assumptions about the presents and futures of Turkish algal biofuel projects.

As I analyzed my interview transcripts when I returned from fieldwork, I realized that when Turkish scientists talk about not being ready, they are referring to the "untimeliness" of algal biofuels. Stated differently, these scientists believe that while Turkey may not be able to develop its algal biofuels sector at present, it may be able to do so in the near future. Close readings of my interlocutors' stories pushed me think differently about their assessments for investing in algal biofuels research. Rather than calling up well work critiques of development, their stories make me wonder: *how are imaginaries of Turkey, as a country with untapped potential, connected to Turkish scientists' potentiation of algal biofuels?*

[115] When I write Turkish scientists, I refer to both scientists working in the fields of "basic sciences" and engineers. In the Turkish context, "scientist" (*bilim insanı*) refers to a general category of people who professionally work in any field of "science." That's said, I will also flag "engineers" when it asks for peculiar attention. Overall, this chapter hinges on engineering as a cultural phenomenon.

This chapter does not simply add another account to the story algae's potentiation. It intends, rather, to open a ground to rethink the rhetoric of potential and potentiation processes. I consider it to be a thought-experiment. It does not make specific conclusions, but is an attempt to generate new questions about the potentiation of life forms. Previously, I documented how researchers potentiate algae and sustainability through their stories, practices, opinions, and feelings. I was motivated because I care about ecology: I wanted to challenge the reduction of life forms into mere commodified resources under the pretense of sustainability—a rhetoric that persistently constrains life into the terms of techno-managerial and economic fixes. I emphasized how algae's potentiation is a labourious process, and how sustainability is made in some ways, to the exclusion of other ways of imagining relations between humans and nature. These processes, however, are often obscured as designs for sustainability are driven by desires for efficiency.

In this chapter, I aim to make visible another form of labour. Here I am concerned with the labour of Turkish scientists. I care about science. As a Turkish citizen and a scientist-in-the-making, I care about the ways that scientific research takes shape in Turkey.[116] From this vantage point, my goal in this chapter is to unpack how Turkish modernity gets made through technoscientific discourses and practices. I ask: what is the Turkish experience with modernization? How does technoscientific culture form and inform questions of Turkish modernity? The chapter will shed light on these questions by investigating simultaneously the potentiation of algae and the potentiation of Turkish scientists in their efforts to modernize the biofuels sector and Turkish technoscience.

Occasionally, something telling would occur during conversations with my interlocutors. Whenever I asked an interlocutor why he or she believed that Turkey does not meaningfully

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[116] Although this chapter is not directly related to the politics of science in Turkey, my aim here is to make my positionality clear.

invest in biofuels, I frequently received a half-hearted response: “Well, you know, Turkey is the kind of country where…” I learned to listen for the subtexts of these suspended silences. Although these silences could carry multiple meanings based on the conversation’s context, inside of these trailing sentences, I heard suggestions that urged me not to be surprised about what happens in Turkey. I realized that each pause could tell a distinct story of Turkey’s experience with modernization. These silences figured Turkey as a country where nothing endures and everything constantly changes. For example, one of my interlocutors noted, “Turkey’s lack of investment in biofuels does not mean that it will continue to be so. Tomorrow, new legislation could suddenly be passed by the government in support of biofuels.” In these conversations, I learned that it was impossible to track constant changes in the Turkish biofuels sector despite the state’s seeming lack of investments in renewables in comparison to fossil fuels.

Nevertheless, my interlocutors’ silences reveal much about what is said or left unsaid about state interventions, or lack thereof, into biofuels production. During our conversations, my interlocutors were aware—as was I—that Turkey invests heavily in fossil fuels under the rubric of development. Stated differently, the state’s centralist and growth-oriented industrialist energy policies are a stabilizing force that largely shapes the nature of energy investments in Turkey. In this context, the charged silences of my interlocutors may be read as indicators of both constant change and endurance, in ways that resonate with geographer David Harvey’s reading of modernity.

In *The Condition of Postmodernity* (1991), Harvey draws attention to the fact that modernity is about fragmentation, change, and ephemerality. In conversation with Marshall Berman’s (1988) *All That Is Solid Melts Into Air*, Harvey notes that to be modern is to be part of a world in which feelings of continuity, endurance, and stability are always interrupted. From this perspective, modernist desire is predicated on a craving for constant change and newness. Yet, Harvey also notes that modernity is, at the same time, about the search for something eternal, steady, stabilizing, and timeless, a desire that is expressed in, for example, the creation of myths and never-ending stories. Thus, modernity is the union of the ephemeral and the enduring. It creates visions of eternal things, ideas, and feelings in a constantly changing world. By extending this analysis to the case of algal biofuels research in Turkey, I revisit the contradictory assumptions that Turkey is both "not ready" for, yet must "catch up" to, international biofuels development. These stories are never-ending. In order to unpack these embedded, internalized, reproduced contradictions, I ask: what does this juxtaposition teach us about Turkish modernity?[117]

Literature on modernity is broad and encompasses various analytics ranging from institutional theories of modernity (e.g., Marx, Weber, Durkheim, and Simmel), to discussion of late modernity (e.g., Beck, Castells, and Jameson). Furthermore, scholars have largely discussed how to explore the question of modernity in different sociocultural localities. For example, the language of "alternative modernities" came to delineate a heterogeneity of experiences with modernity (e.g., Ashcroft, 2009; Gaonkar, 2001; Gluck, 2011; Kumar, 2009). By contrast, others intended to show how modernity, as a universal ideal, was actually produced out of heterogeneous experiences with modernization (see Mitchell ed., 2000). In this chapter, I focus on modernity, not as not object of analysis per se, but as an analytic framework through which I explore people's relationships to and with their materials worlds. Put differently, I examine how the modernization process is unfolding in Turkey, not in comparison to "other" modernities, but

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[117] Although there exist different readings of modernity and modernization, here I follow sociologist Jurgen Habermas's account. I refer to the difference between "modernity" and "modernization" by approaching modernity as a project, and modernization as institutional and structural changes that makes modernity possible. Also, see Çiğdem, 1997: 68.

rather as a technoscientific contextualizing force that underscores the particularity of localized algal biofuels research. As such, I treat Turkish modernization as a technoscientific process—I do so through examining how material and social relations shape, and are shaped by, the Turkish experience with modernization.

This chapter approaches the relationship between modernization and algal biofuels as one point of entry undertaken by Turkish scientists. I flag scientists' labour in potentiating modernity through algal biofuels projects, which are otherwise marginalized in government policies. My fieldwork findings revealed that Turkish biofuel scientists often go beyond their roles as researchers to shoulder the responsibility of building a sustainable Turkish biofuels sector—and, by extension, a sustainable Turkish nation-state. Although Turkish scientists-as-researchers are involved in different sectors ranging from coal to geothermal energy, their role in the biofuels sector is remarkable in the sense that they are the major players in making biofuels matter in the Turkish context. This scenario is distinct from the oil sector—where corporations take the foremost lead alongside state institutions—and unlike the wind and solar energy sectors—which are shaped by the activities of civil society, state, and corporations. What my fieldwork makes clear is that the biofuels sector is actively sidelined by the state, whose renewable energy policies focus instead on hydropower, wind, solar, and geothermal, above bioenergy initiatives. While the absence of the Turkish state's investments in biofuels has created a vacuum in science and energy policy, Turkish scientists have sought fill this void by modeling biofuels in their imaginaries of modernity. My fieldwork experiences, especially in the participation of conferences, revealed me the peculiar role of scientists in the making of bioenergy economies in Turkey.

During my fieldwork studies, I attended ten conferences on the Turkish energy sector, renewable energy infrastructures, biofuels, and algae. These conferences played a particularly important role for my research. First, these conferences allowed me to observe how networking takes place inside the Turkish scientific community. I was able to see the interactions between different actors in the community, while getting a sense of current biofuels and algae research trends as they unfolded in real time. Second, conferences served as a gathering point for community members. In a field where many researchers work in small teams or in isolation, I was able to see how conferences provided a space for scientists to build consensus about what gets to count as research worth pursuing in Turkey. Thirdly, from a practical standpoint, conferences were a good fieldsite to investigate these interactions. They were the main venues to follow up and observe how algal biofuels related discussions were taking shape.

When I began my fieldwork in Turkey in the summer of 2014, however, no conferences on algal biofuels had been convened. By 2015, this situation had changed as a number of conferences, meetings, and symposia were announced. In July 2015, for example, the *International Conference on Microalgae and Biofuels* was held at Koç University, Istanbul. Additionally, in May 2016, the *Second Algal Technology Symposium* organized by Prof. Meltem Conk Dalay from Ege University, İzmir, expanded upon an earlier conference held in 2011. Strikingly, the 2011 conference did not include any papers on the subject of algal biofuels. However, the 2016 symposium devoted an entire panel to the topic. These events, and the speed in which they have taken place, signal a rising awareness of algal biofuels research in Turkey among established and upcoming scientists. What has become clear in these happenings is that, despite the political economic vacuum surrounding biofuels policy in Turkey, Turkish scientists are making algal biofuels matter through their own approaches to modernity and science. This chapter's goal is to show how Turkish scientists potentiate algae in bioenergy economies, and make Turkey place in the world scene of biofuels visible.

This chapter is divided into two halves. In the first half of this chapter, I will explore the ways that the imaginaries of modernity and modernization are connected to visions about "Turkey's untapped potential" in the biofuels stories of the Turkish scientists. I will first highlight the tension between national interests and global efforts in the making and unmaking of the Turkish biofuels sector. In this light, I will discuss the way that the Turkish experience of modernization is bound up with Westernization, or more precisely, what I am calling *nationalized Westernization*, to generate a potentiating force in shaping the futures of biofuels in Turkey.

Subsequently, I will bring to the fore the experiences of Turkish scientists as the engineers of both infrastructures and consensus. From this vantage point, I will describe algal biofuels projects in terms of these scientists' quotidian, practical, and technical concerns. This approach reveals another form of modernization that I refer to as *pragmatic modernization.*[118] Furthermore, this analysis seeks to understand why Turkish scientists embrace algal biofuel projects despite the seemingly absence of political support for these new projects. I will conclude the first half of this chapter by contemplating the rhetoric of potential, which makes itself visible in the imaginaries of Turkey's interstitial position between an agrarian and an industrial society, and between the East and the West. In the light of this analysis, the next half of this chapter will turn to algal biofuels researchers' distinct but also entwined stories from the field in order to delineate the link between algae's potentiation and the potentiation of modernity in Turkey. I will flag three main projects to understand why, how, and to what end, Turkish scientists invest in algal biofuels projects. This chapter intends to make visible the labourious efforts of Turkish scientists in the making of algae bioenergy economies in Turkey, in order to show how they

[118] Tanıl Bora (2017) also talks about pragmatic modernization (*uygulamacı-faydacı modernleşme*). However, my employment of this term does not necessarily follow Bora's analytic. I refer to his account when applicable.

potentiate a form of modernity. My aim is to show how their labours unsettle conventional perceptions that bioeconomies are all modeled on the image of the West (cf. Cooper, 2008; Sunder Rajan, 2006). Overall, this dissertation, thus aims to de-naturalize ideas about the "inherent potential" of the West as a model to stand as a proxy for all bioeconomies, while it simultaneously troubles the vision of algae's potential as a sustainable energy resource as natural and innate.

Potentiating Scientists, Modernizing Biofuels

We all talked about policy...The first thing I want to show you is what I'm wearing. My wife makes all my Hawaiian shirts. And this is the theme of things, it is clocks and she also makes my tie; this is...a time machine. This is the theme to start thinking about the future...

Image 4 A Scientist Performing
Photo by the author taken during the Atlantic Council Energy and Economic Summit

In November 2014, I attended the Atlantic Council Energy and Economic Summit held in Istanbul. As a participant, I listened to state agencies, policy-makers, and scientists from different parts of the world talk about the "presents" and "futures" of both global and regional energy policies, investments, and infrastructures. On the second day of the summit, I joined a plenary session entitled, "Innovation in Energy Technologies." This was a special session hosted in partnership with the MIT Energy Initiative. When Alexander H. Slocum, a professor of mechanical engineering at MIT, took the stage, I had a moment of déjà vu. I just had listened to Slocum give a comparable talk at the 2014 MIT Energy Conference just eight months earlier.

Both of Slocum's talks covered similar terrain. In both presentations, he discussed his work on "symbiotic energy harvesting and storage systems." These "symbiotic systems," Slocum proposed, were an amalgamation of several different energy sources, such as wind, solar, nuclear, and oil. He even began his talk, as he did at the MIT conference, by speaking about his clothes and what they represented. Despite the similitude of these talks, a notable distinction between the two was how Slocum chose to conclude his Istanbul presentation. At the MIT Conference in Cambridge, Massachusetts, Slocum gave recommendations for how the United States should address its energy security policies. At the Istanbul Summit, he wrapped up his presentation with a slide that read, "Turkey as the Region's Energy Leader!"[119]

This slide did not sit right with me. In that moment, I could not understand why I felt such a strong reaction to a seemingly innocuous slogan. This was a markedly different response from what I experienced at Slocum's presentation in Cambridge. At the Istanbul conference, Slocum noted that while Turkey has no oil reserves, it could generate energy through the installation of offshore wind farms combined with solar energy systems. "I think Turkey could really lead the renaissance in the whole Mediterranean Basin," he contended, "because you have the technology, you have the manufacturing history." He invited his Turkish audience to "take this idea, create the vision and say 'you know what, we are gonna show the rest of the world how to do this.'"

Later, I realized that my reaction was part of an embodied, well-cultivated attitude I had to invocations of "the West." I was taken aback by an American scientist telling Turkey what to do. As a researcher doing ethnography at home, I recognized my visceral response was one that had been cultivated over a lifetime in Turkey, where the West is represented as both friend and

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[119] Promotion of Turkey as a model for the region by the West is not new. Several Western scholars have written of Turkey as a "successful" model of modernization. Daniel Lerner's *The Passing of Traditional Society* (1958) is one such example. "Turkey's apparently successful adoption of western norms, styles, and institutions…was portrayed as testimony to the viability of the project of modernity even in an overwhelmingly Muslim country" (Bozdoğan & Kasaba 1997: 4). Furthermore, in the 1960s and 1970s, Western diplomats and press circles also presented Turkey, "as an appealing model of social reform for the Central Asian republics of the former Soviet Union" (ibid: 5).

foe. Sociologist Murat Ergin (2016) considers this paradoxical vision of the West as a "creative, yet schizophrenic approach" (p. 19). I am interested in the history and development of this rhetoric rather than its psychological underpinnings. While reflecting on my reactions to Slocum's presentations, I began questioning how this rhetoric of the West participates in the localized potentiation of algal biofuel projects.

After the session, I headed to the terrace for some fresh air. As I took in the view of the nearby Bosphorus Strait, I overheard several attendees discussing Slocum's presentation. Based on their conversations, and despite my own reactions, I concluded that Slocum was successful in persuading his audience of "Turkey's potential." The attendees seemed to be convinced about his idea for offshore wind farms.[120] This response led to another series of questions: what work does convincing people do for algal biofuel projects, and why does this matter for biofuel practitioners in Turkey?

Several times during the two-day summit, I stopped to pick up a few pamphlets and magazines that were left on display at the lobby's information kiosk. I wanted to read up on up-and-coming actors and practices in the Turkish energy sector. While scanning through a magazine published by the Turkish Ministry of Energy and Natural Resources, I paused to look at the advertisement, "Turkey, Discover the Potential." I later learned that it was the slogan of a new Turkish branding program. The Turkish Exporters' Assembly (TİM), in coordination with the Turkish Ministry of Economy, initiated the program to promote "Turkey's potential" on the

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[120] Around the time of Slocum's talk, the US Secretary of Energy, Ernest Moniz, and the Energy Minister of Turkey, Taner Yıldız, indeed signed an agreement to improve wind energy cooperation between the US and Turkey ("Turkey, US ink wind energy deal at Atlantic council summit," 2014). This raises new questions about the relation between scientists and politics, which go beyond the scope of this chapter.

world stage.[121] With this revelation in mind, I began questioning how the rhetoric of potential works to activate algal biofuels projects in Turkey. More broadly, I questioned what this rhetoric could tell us about Turkish modernization.

This summit turned out to be foundational for my research in several ways.[122] First, it took place during the early stages of my fieldwork in Turkey. It helped me reformulate questions about my research on Turkish algal biofuels projects. Second, it also gave me the chance to observe how encounters with the West shaped Turkey's energy sector. I take Slocum's advocacy for Turkish wind farms and people's subsequent interest as a prime example. Thirdly, this conference gave me the opportunity to approach the rhetoric of the West not "as an abstract and distant model, but in the form of direct encounters and interactions" (Ergin, 2016: 5). I learned to see different the ways that Turkish modernization is bound up with Westernization.

This section starts with the suggestion that the rhetoric of potential has always been an activating force in the Turkish modernization. I will first elaborate on how Turkish modernization is bounded up with Westernization in Turkey. From this vantage point, I learned to listen for the tensions that arise between national energy interests and energy policies of the European Union. The following sub-section, Infrastructures, will flag the pragmatic character of modernization process in Turkey. I question why and how Turkish scientists embrace algal biofuel projects. The last sub-section will reflect on the rhetoric of potential, and the way it potentiates not only biofuels but also Turkey's geopolitics.

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[121] TİM organized the launching ceremony of this program in September 2014, and afterwards the branding began to spread in various venues, including international conferences.

[122] Yet, I almost missed this opportunity, as participation in the summit was by invitation only. By chance, a mutual contact recognized me outside the conference and was able to let me in.

Westernization

Although the Turkish biofuels sector's origins stretches back to the birth of the Republic,[123] the government has only recently included biofuels in its renewable energy policy agenda. This inclusion was mandated as part of Turkey's membership negotiations with the European Union (EU). In 1999, Turkey officially became a candidate for EU membership, and this candidacy has initiated large-scale changes in Turkish policy.[124] These changes were meant to bring the country in line with EU member-states' political economic and sociocultural standards. They included the adoption of "policies, directives, standards and norms in the EU designed to stimulate and support of the biofuels industry" (Erdoğdu, 2008: 2187). This intensive reshaping of Turkish policies has coincided with the rise of biofuels' popularity within the package of various institutional and economic changes required from the EU (Acaroğlu et al., 2015: 1179).[125]

This trajectory, shaped through the EU membership process, illuminates how the relations with the West have activated the Turkish biofuels sector. This potentiation, however, was not a success story. In the midst of membership negotiations, formally productive Turkish biodiesel facilities began to be shut down.[126] Why did this occur? Through investigating this question, I will explore the Westernization process that is connected to the modernization of biofuels in the Turkish context. Although biofuels development carries with it stories of progress

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[123] See the following sub-section, "Infrastructures," for the earlier history of biofuels in Turkey.
[124] Turkey has been an associate member of EU since 1963.
[125] The difference of this Westernization process from the early Republican period should also be acknowledged in light of the intensive institutional and legal restructuring required in order to adapt political, economic, and sociocultural structures to the European Union principals—namely, structures ranging from environmental policies to education (e.g., see Canefe & Uğur, 2004). Further, it was through this process that neoliberalization process came to be intensified in Turkey, following the 1980s economic liberalization policies.
[126] Under the 2013 Petroleum Market Law, biodiesel and bioethanol first took their place in the blended transportation fuels in Turkey (Aytav & Koçar, 2013: 341). Biodiesel is commonly blended with petroleum diesel, and bioethanol is with gasoline. There is one Turkish company producing biodiesel via oil crops. Bioethanol production facilities, which do not count more than five, produce biofuels mainly via the crops of sugar beets and corn, and their residues.

and modernity, these stories may contradict local iterations of development. This is the case in Turkey, where biofuels must contend with the modernization brought forth through the state's dependency on fossil fuels.

Scholarship on Turkish modernity identifies the beginnings of Turkish modernization with the introduction of the Kemalist project in the 1920s; a project named after the founder of the Turkish Republic, Mustafa Kemal Atatürk. The Kemalist project's goal was to "bring Turkey into the European economic, cultural, and political milieu as an equal partner" (Nalbantoğlu, 1993: 67). In the eyes of Turkey's modernizing elites, the country was "behind" its Western counterparts and needed to catch up to their developments—especially in the fields of industrialization and technological advancement. As sociologist Çağlar Keyder (1997) has argued, these modernizing elites had "readily identified modernization with Westernization," and had located it inside European civilization (p. 37).[127]

How is Westernization bound up with Turkish modernization? Political theorist Hasan Bülent Kahraman (2002) has argued that although Westernization was primarily a metaphor for these elites, it became the *agent* of modernity that transformed Turkey's political, social, and cultural structures (p. 126). I find sociologist Meltem Ahıska's (2010) interpretation of Occidentalism a helpful analytic for unpacking the potency of Westernization within the Turkish context.[128]

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[127] Scholars have largely examined the identification of modernization with Westernization through different analytics ranging from social engineering to nationalism. For example, see Cizre-Sakallıoğlu, 1994; Kadıoğlu, 1996; Mardin, 1973; Navaro-Yashin, 2002.

[128] Ahıska also notes that Occidentalism is a contested term. She draws attention to how this term came to signify anti-Westernism, especially after 9/11 (Ahıska, 2010: 4). For Ahıska, such different connotations of Occidentalism do not constitute a confusion or controversy, rather they "reveal something very important"—that is, "the historical doubling of Orientalism and Occidentalism both in the West and the non-West."

Ahıska employs Occidentalism to emphasize how discourses on modernity operate as "entangled representations of Western definitions of the East, or the East reacting to the Western gaze" (Ahıska, 2010: 5). She elaborates this point by figuring Westernism and anti-Westernism as "distorted mirror images of each other." While Westernism refers to the desire for "catching up with the time of modern history," anti-Westernism becomes "a way of restoring the authenticity of the past lost due to modernization" (ibid: 41).[129] Markedly, Turkish sociologist Murat Ergin (2016) interprets the co-existence of Westernism and anti-Westernism as the "paradox of authenticity and Westernization" (p. 17). This corresponds with debates over how modernization, as a process, unfolds in postcolonial countries.[130] To illustrate this point, I draw on a story about the failure of biofuels in Turkey, as told by my interlocutors. This story exemplifies what I call *nationalized Westernization.*

During fieldwork, I learned something surprising about the history of biodiesel production in Turkey. When I asked my interlocutors why biodiesel production facilities began to shutter in 2005, they gave me several conflicting reasons. In their stories, I heard several

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[129] During fieldwork, I encountered multiple stories that include the rhetoric of Westernism and anti-Westernism. One notable example appeared while I was conducting archival research in the library of TÜBİTAK Marmara Research Center (MRC). During this research, I came across the memoirs of Mehmet Nimet Özdaş (1998)—the secretary general of TÜBİTAK who played an important role in the establishment of the MRC. In his memoir, Özdaş details how the establishment of the MRC was based on "successful models" of research councils in the "West" (Özdaş, 1998: 40). Yet, he was careful note that it was not about imitating the West. Rather, Özdaş claimed that the proposal for the MRC was a "Turkish Synthesis" that was developed through their "own specific planning [while] being open to any kind of development" (ibid: 63). The trope of "Turkish Synthesis" can be seen as a form of nationalized Westernization—which I will explore in the following pages.

[130] Scholars employ different terminologies when they refer to the positionality of Turkey in relation to the West, most notably, non-Western and postcolonial. These uses all have their own politics that go beyond the discussion here. Nevertheless, Turkey can be approached in the postcolonial context through the analytic of resentment. Against arguments that Turkey "did not suffer from resentment because it was never colonized," Ergin (2016) explains: "Let us remember that modernity was imported into Turkey's imperial precursor, the Ottoman Empire, through Western diplomatic pressure, economic domination, and periodic wars to such an extent that the entire process can be summed as "the growing influence of Europe in the Ottoman Empire and the reactions it brought about in the Ottoman state and society" (Zürcher 1993: 2)…After a War of Independence between 1919 and 1923 that is even today considered to be fought against the "West," it is no surprise that a discourse of penetration…lingered" (p. 18).

dynamics at play. First, despite the state's outward acceptance of biofuels as part of their EU membership process, there were few if any tangible policies in place to regulate local projects. In spite of governmental incentives for biofuel production which encouraged people to enter into the business, most of the biodiesel production was unlicensed (*merdiven altı üretim*), and there were no standards or regulations. For example, one interviewee noted that, "people were producing biodiesel in their homes overnight and selling them in bin[s], in containers." Other interlocutors corroborated this statement. This unlicensed production led to serious consequences, notably physical damage to vehicles that used unregulated biodiesel. Further, another biofuel scientist told me that, "to obtain biodiesel in a much more economical way, people began to import, for example, palm oil from Malaysia." As a country dependent on import trade for oilseeds, this situation created a further burden on Turkey's budget deficit. The Ministry of Agriculture openly resisted biodiesel production in light of these concerns.

Faced with opposition from the Ministry of Agriculture, the Energy Market Regulatory Authority (EMRA) instituted a number of regulations to prevent unlicensed sales and import-based production of biodiesel.[131] The EMRA also later approved biodiesel standards, as specified by the Turkish Standards Institute (Aytav & Koçar, 2013: 342).[132] Until 2015, most biodiesel production facilities had shutdown, with the exception of a single company, the DB AgroEnergy

[131] "Oil Market License Regulation" (2005); "Communiqué on Technical Regulations regarding the Production of Diesel Oil Types, their Procurement by Domestic and Foreign Funds and their Market Supply (Petroleum Products Serial No. 1) (December 2005); "Communiqué on Technical Regulations regarding the Production of Auto Biodiesel, its Procurement by Domestic and Foreign Funds and its Market Supply (Petroleum Products Serial No: 2) (January 2006); Law on the amendments in Income Tax no. 5479 (March 30, 2006).

[132] TS EN 14,214 auto biodiesel and TS EN 14,213 fuel oil biodiesel standards.

Corporation.[133] Notably, this was also the first and only Turkish company to engage in algae-based biodiesel production. The rapid rise and dramatic fall of the Turkish biodiesel sector illustrates tensions between Westernization and nationalization in Turkey's modernizing process.

At first glance, it appears that the Westernization of biodiesel production standards facilitated the mass shutdown of facilities. Yet, this view obscures the Ministry of Agriculture's role in the process. My interlocutors, including biofuels scientists as well state officials working in the General Directorate of Renewable Energy, told me that they were aware the Ministry of Agriculture's recalcitrance toward biofuel production despite the Ministry of Energy's support. It was an open secret. The Ministry of Agriculture had prevented the spread of biodiesel production out of national protectionist interests: they were mainly concerned about the country's already high import rates of oil seeds and crops.

From my interlocutors' conversations, I gathered that it was not the standards requirements that had blocked the success of biodiesel investments. Rather, tensions between ministries obstructed the biofuel production development. I read such ministerial confrontation in terms of nationalized Westernization, which prioritizes national economic interests, as a roadblock to EU membership requirements. This nationalized Westernization revealed that Turkey must resist its dependency on external markets for its own interests. As I will describe later in this chapter, this claim is also relevant for how algal biofuels projects are treated.[134] For now, I turn my attention to another story of Turkish modernization. This story explores the ways

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[133] Founded in İzmir at the end of 2005, DB AgroEnergy is currently the sole commercial biodiesel operation in the country. This begs a further question: why is the DB AgroEnergy Corporation still the only private company in the Turkish biodiesel sector? Although providing an answer to this question goes beyond the scope of this chapter, it is worth mentioning contractual farming that prepared the conditions of possibility for this corporation to continue operating. The similar analytical framework also applied to the case of Konya Sugar, which is one of third bioethanol producing companies in Turkey and meets more than half of domestic bioethanol production needs.

[134] I will expand on this point through a case study of the IMBIYOTAB project. See the section "Modeling."

that infrastructures take shape through technoscientific processes in Turkey, and how these projects illuminate why and how Turkish scientists are likely to embrace "new" projects in the area of algal biofuels.

Infrastructures

I am seated in the sunlit office of Sema, a biofuels scientist at a top Turkish university along the Aegean coast. This was the second time we had met. The first occasion was in 2015, during a workshop on energy farming and biofuels. This workshop was held at the Bursa Uludağ University Technology Development Zone (ULUTEK) and served as a networking hub for scientists interested in Turkey's budding biofuels sector. Sema is excited to tell me about algae and biogas. In our discussion, I learn that biogas is both the most popular and the most established type of biofuel in Turkey.[135] More, Sema confides in me that algae could hold the key to future advances in the national biogas sector. Despite her enthusiasm for the subject, I was surprised when she struggled to explain the project's seemingly insurmountable hurdles. She stumbled when told me her qualms over the lack of public appearance and approval for algae-based biogas systems.

Sema's worry for biogas's acceptance differs from biofuels scientist Mehmet's exasperation. "In rural areas," Mehmet explains, "people still burn *tezek* [dried dung]; how would you convince these people to produce algal biofuels?" I ponder his question. Both Sema

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[135] Biogas production via processes known as "waste valorization" is a profitable business in Turkey (Also, see Demirer's project in Chapter Three). The analysis of this sector deserves a separate research that goes beyond the scope of this research. Nevertheless, I wan to provide you a sense about the shape of this sector on the basis of my fieldwork experience. During my fieldwork, I was able to identify a number of industries that already operate in sectors other than energy can commodify the waste from their production process in the form of electricity produced via biogas. While visiting the biogas production facility that belongs to a Turkish dairy industry Sütaş, I wanted to learn whether and how the neighboring factory utilized the electricity produced by this facility. I was surprised that they do not meet the factory's electricity needs with this facility, and so I inquired further. The answer was simple: the electricity they buy from the grid is cheaper than the electricity they sell to the grid. As a result of this price difference, for corporations like Sütaş biogas production constitutes a way to accumulate capital by production and realization—that is, a transformation of commodified waste into money by trading it on the electricity market.

and Mehmet are concerned with how to convince people of algae's value. Mehmet believes that rural people are too "underdeveloped" to grasp biogas systems in Turkey. Sema, however, is more anxious about whether these projects will "work" or not. Her concerns are about getting people to not only adopt but embrace biogas technologies. Underpinning both Mehmet's developmentalist perspective and Sema's concerns, is the shadow of past failed biogas systems.

In this section, I investigate how infrastructures unfold as a technoscientific process to build consensus on Turkish modernization projects. This framework helps me to understand algal biofuel scientists' preoccupations with public acceptance of "new" algal biofuels. As I will explain, this concern for newness, in the case of biofuels, first appeared with the development of earlier state-sponsored biogas systems in the 1960s.[136] Followed the 1980 military coup d'état, projects were mostly dismantled. My interlocutors' stories convey how the specter of these "failed" projects overshadows how new systems are received in Turkey today.

Sema's story tells about the hurdles Turkish algal and biogas projects face. Her story reveals that their creation is not just a technical concern, but also a social one. Public consensus is critical for the acceptance or rejection of each biogas project installed in rural people's localities. Scientists and engineers must learn to build not only good devices, but good social relations. This consensus building through working infrastructures is what I term *pragmatic modernization*—that is, modernization practices based on daily, practical, and economic needs, as well as on an idealized model of the nation-state (Bora, 2017: 79). Mehmet and Sema's stories hint at the alternate models of modernity that take shape inside of biofuels stories.

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[136] In 1957, the state-led Soil and Fertilizer Research Institute (SFRI)—now the Soil Fertilizer and Water Resources Central Research Institute—launched its first investigations into the feasibility of building biogas systems in rural Turkey. By the 1960s and 1970s, several initiatives were underway: pilot plants were established in state facilities; the Ministry of Development and international institutions—including the World Bank—provided funding; and almost one thousand systems had been established (There is no concrete number regarding established biogas systems. This is the number provided by one of my interlocutors).

Couched in these stories are the fears of repeating past failure like those of earlier, state-sponsored biogas programs in Turkey. These stories emerge out of the framework of development, where failed government projects from the beginnings of the Republic signaled the failure of the Turkish state to modernize. One could also argue that the state "failed" to adapt to western ideals of "progress." How modernization is actualized in Turkey is further related to America's foil to European modernity as the "über-West" (Bora, 2017: 77).[137] This is pertinent to how earlier biogas systems were promoted and launched by the state under the guise of agrarian development during the post-World War II, US-led "Green Revolution."[138]

I return to Sema's story to help me understand why building consensus around infrastructure projects matters. She wanted to make sure that I understood why certain projects succeeded while others had collapsed. Sema tells me that peasants' resistance towards new technologies led to their failure to adopt biogas systems. She believed that this resistance was the reason behind the deactivation of early biogas systems. For Sema, non-automated biogas systems—such as those built in China or India as part of a "Green Revolution"—could not work in Turkey's rural areas. She explained that the systems for the Turkish rural areas should at least be semi-automated. "It is hard to get peasants to regularly deal with them," she tells me. "For example, [you have] to ask them [to mix] the substrate in the tanks on a regular basis." According to Sema, for systems to function daily, they need to be designed with a consideration for the sociocultural realities of localities. Sema's story reveals that the desire to "catch up with

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[137] As Bora (2017) explains, the United States provided another silhouette of the West in Turkey, which represents "easy, fast, and briefly and to the point modernization" (p. 81). The perception of the West in the image of the US did also exist in the early years of the Republic, especially in reference to the President Wilson's support for "the self-determination of nations" (Bora, 2017: 78). Yet, the image of US became institutionalized as an alternative reference of the West during the Cold War era basically through an anti-communist ideology (ibid: 79).

[138] Turkey received so-called Marshall aid which the state used to investigate new tools to increase agricultural productivity (Aydın, 2010; Ulukan, 2009).

the West" by modernizing biogas systems does not suggest a "mere adaptation" of transferred technologies. Rather, these new technologies must fit within a culture's local needs. Sema's emphasis on "locality" is a question of practicality. For the systems to work, new technologies need to be rendered local by convincing people of their worth.

Furthermore, Sema suggests that a good working model needs to be established before peasants would embrace these new biogas systems widely. Similarly, many of my interlocutors echoed the importance of building "good models." They noted that, "you cannot recruit people, whether farmers or industrialists, to participate in projects if they have yet to see that these projects work on the ground successfully." The following statement usually complemented that claim: "if a project has failed once, it is hard to re-launch it or convince people that it can work another time." What I hear in this story is that people need to be convinced about algal biofuels production systems working before they will accept their implementation in Turkey.

To convince, or to be convinced, is also a question of consent. Ethnographic studies of nationalism and the Turkish state examine the ways that the Turkish state galvanized its legitimacy and continuity through brute modernization, despite the assumption that change is inevitable. [139] It was through this "aspiration to modernize" that the state was able to amalgamate an "internally-fragmented society" into the country of "Turkey" as we know it today (Akbulut & Adaman, 2013: 3). To achieve people's consent, the state represented itself as "the deliverer of modernization" and the politicians and their governments heavily invested in large-scale infrastructure projects ranging from roads to dams (ibid: 4). Politicians—including Süleyman Demirel, a former prime minister nicknamed the "king of dams"—have emphasized that infrastructures are not merely civil engineering projects, but are sociotechnical projects. The way

[139] For example, see Altınay, 2005; Bozdoğan, 2001; Bozdoğan & Kasaba, 1997; Knudsen, 2010; Özkan, 2013.

Turkish state promoted dams is illustrative to see how the modernity project unfolds in Turkey as a technoscientific process. In relation to one of the biggest dam projects in Turkey, the Southeastern Anatolia Project (SAP), Demirel noted:

> The love of [SAP] is the love of Turkey. [SAP] is the cement that unifies Turkey; it is the largest project of the Republic. […] It is beyond an engineering project […] It is a struggle to make people happy. It is not only about taking water from rivers and bringing them to the plains. That is just a part of the big picture. It includes the education of people; their preparation for a new world, for the conditions of a new world (quoted in Akbulut & Adaman, 2013: 4) .

Attending to Turkish experience with modernization as a technoscientific one, the relation between infrastructure building and consensus building deserves deeper reflection.[140] Historian and STS scholar Paul N. Edwards' (2003) inclusion of analyses of scale in infrastructure studies is helpful here. Edwards notes that, "infrastructures simultaneously shape and are shaped by—in other words, co-construct—the condition of modernity" (p. 186). He proposes that an investigation into infrastructures should overcome "modernity theory's typically meso-scale perspective," which focuses on large institutions as the main actors in infrastructure development (Edwards, 2013: 221-222). A meso-scale analysis of infrastructure projects renders these phenomena as inaccessible to individual or group critique, or, as Edwards suggests, beyond "social action" (ibid: 221). On the other hand, he argues that a multi-scalar approach can illuminate how people engage with infrastructures. It is from this vantage point that Sema's and rural people's different engagements with infrastructures can be rendered visible. Furthermore, the more I think about Sema's story, the more I shift my attention from how the Turkish state gains its legitimacy through infrastructures to elucidating how consensus building is attained

[140] Infrastructure's key place in modernization processes is not unique to Turkey. Scholars have largely explored the entwined relation between infrastructures and modernity, for example, see Edwards, 2003; Larkin, 2013; Vernon, 2014.

through the act of building infrastructure.[141] The state is not alone in this project of consensus building. What I hear in Sema's story is that Turkish scientists over time have also enacted consensus building to motivate their projects. As I learned through social science studies of Turkish modernity and modernization, this history can be traced back to the early years of the Republic.

Turkey's history of modernization extends back to the Ottoman era where it began as "an elite-driven, consensus-based, institution-building process" (Bozdoğan & Kasaba, 1997: 3-4). Amid Westernizing reforms launched from the mid-1920s to the 1930s, early republican elites aimed to craft deliberate "breaks" in previously shared histories with the Ottoman Empire, as well as the Middle East, and Islam (Nalbantoğlu, 1993: 67). The founding elites of the new nation-state were "[marching] toward[s] a secular modern society": where any and "all social and cultural reminders of the pre-republican period," for example, the Arabic alphabet, "were being replaced by imagined signs of Western modernity [e.g., Latin script]" (ibid: 71). They were in hurry for the inauguration and implementation of reforms. Dissenting voices that called for an understanding of modernization as a slow and labourious process were muffled (Bora, 2017: 86). In his biographical novel woven around the life of a Turkish civil engineer Mustafa İnan (1911-1967), distinguished Turkish novelist, Oğuz Atay (1934-1977), details how accelerated modernization efforts appeared through the eyes of an engineer:[142]

> Everything was changing every day. First, the alphabet changed; a totally new writing appeared… Mustafa İnan thought about this issue in his own way. Was it necessary to fight at so many different front lines? [...] It was of great value to know a little bit about everything.

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[141] Infrastructure building as a modernizing force and cementing the power of state—which still shapes the contemporary Turkish political environment—cannot be ignored. In my future projects, I want to pursue this line of research.

[142] As the Turkish writer Tanıl Bora (2017) notes, the topic of Westernization becomes clear in Turkey with its affective complexities. That's why its dynamics can be understood in the Turkish literature more than through the political texts (p. 109).

> Everyone knew about everything. Everyone grasped everything… In the first years of the Republic, the tireless *professors of everything* generated an ever increasing number of theories… Both significant and insignificant doors to the West suddenly opened. Everything was new; everything was heard for the first time. Hence, people embraced everything together and desired to learn everything, all at once. Even healthy minds were contaminated by *the sickness of knowing everything*… (emphases are mine; Atay, [1975] 2004: 74-76) [143]

Atay's script, in a literal sense, is grounded in the graphical and textual departure from the Arabic to the Romanized alphabet during the establishment years of the Republic. His historical retelling centers on what he calls, "the sickness of knowing everything."[144] I recalled the above passage from Atay's novel while interviewing environmental engineer Prof. Göksel Demirer. Atay's words echoed in my mind as Demirer told me, "engineers are the scientists who know about everything as required." I read this demand to know everything as part of Turkish scientists' response to change. The rhetoric is useful of understanding how "new things," such as algal biofuels, are embraced by Turkish scientists. Like rural peoples, scientists must also be convinced to embrace new projects and accept new infrastructures.

The more I tuned into the earlier history of Turkish modernization, the more I realized how this rhetoric of "knowing everything" is embedded in the modernization process. Tanıl Bora (2017) examines this rhetoric by referring to a letter Ahmet Midhat (1844-1912), an Ottoman journalist, addressed to his son on the guidance of Ottoman intellectuals (p. 28). In the letter, he advised his son to "know something about everything." Bora argues that Ahmet Midhat's advice is understood as a form of optimism that underlines American philosophy (Bora, 2017: 82). For Bora, this advice can also be registered as a kind of Turkish philosophy that stands at the heart of advocacy for *pragmatic modernization* (ibid: 82-83). This modernization forms the very basis of

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[143] Translation is mine.

[144] The texture and content of Atay's contention differs from what historian and STS scholar Rosalind Williams (2002) refers to engineering in the form of "Profession of Everything." Atay's framing of "knowing about everything" is more a critique of opportunism than of technological determinism as Williams criticizes.

what I call engineering culture in Turkey. Being an engineer is not about professional capacity, but about thinking, acting, feeling like an engineer. In what follows, I will elaborate on this point to examine how Turkish scientists use engineering to craft their algal biofuel projects. In this way, I will make visible how and why Turkish scientists embrace algal biofuels projects despite the lack of state support.[145]

Engineers have been the primary actors in the Turkish modernization process. A notable example is the aforementioned "king of dams," Süleyman Demirel (1924-2015), who served both as a prime minister and president of Turkey, and who was also a civil engineer.[146] Demirel was not the only Turkish engineer-cum-President. Turgut Özal (1927-1993), who was responsible for the liberalization of the Turkish economy in the post-1980s, was an electrical engineer.[147] As Köse and Öncü (2000) note, engineers in Turkey were not just technical actors, but were integral to the "welfare of society."[148]

Scholars working on engineering and engineers in Turkey have shed light on (1) the rise of engineering in the Turkish context, (2) the identity and class position of engineers, and (3) the revolutionary character of Turkish engineering. This scholarship has also illuminated the historical, nationalist endeavours of engineers. This fourth aspect was surprising to me. Owing to my father's background as a craftsman, I had cultivated a certain idea of how engineering, as a practice, had unfolded in Turkey. This scholarship helped me to understand how Turkish

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[145] This point can be further elaborated to re-think about the vision of Turkish modernization as a top-down process. By this note, I do not suggest that the way Turkish scientists undertake projects out of their own volition presents a form of modernization practice from-below. It is also another question to follow during my post-doctoral research.

[146] Demirel also served as the 9th President of Turkey from 1993 to 2000. He previously served as the Prime Minister of Turkey seven times between the years 1965 and 1993.

[147] Özal was the 8th President of Turkey from 1989 to 1993. He previously served as the 26th Prime Minister of Turkey from 1983 to 1989.

[148] Against the arguments that propose the rise of engineering in the Turkish context as a direct result of industrialization process, sociologist Nilüfer Göle [2012 (1986)] stressed the 1830s when a series of Ottoman Era engineering schools were opened. "The purpose of these institutions was to educate a corps of engineers that would protect the empire and modernize the military body" (Göle, 2012: 112).

engineering and the state were co-produced as form of pragmatic modernization. Sociologist Nilüfer Göle (2012) drew my attention to how engineers' nation building projects were nurtured during the establishment years of the Republic. During this industrialization period, engineers took on the role of managers in the absence of a managerial class. Göle provides a nuanced interpretation of these manager-engineers as a historically contextualized phenomenon in Turkey, distinct from contemporary forms of entrepreneurship. She makes visible how the goal of "emancipating the nation" cultivated nationalist sensibilities of engineers. These sensibilities, in turn, reflected their developmentalist ideals (Göle, 2012: 113). Drawing Göle's analysis into conversation with the rhetoric of "knowing everything" helps understand how and why my interlocutors embrace of algal biofuels. It reveals how Turkish engineering has historically operated, and continues to do so, at the juncture of nationalized Westernization and pragmatic modernization.

Although much has changed since the founding of the Turkish Republic, including the roles of engineers,[149] the culture and spirit of Turkish engineering has endured. In this section, I have highlighted this spirit of Turkish engineering culture. Drawing on several examples, I have demonstrated how the technical and social aspects of engineering take place simultaneously. Notably, I have drawn attention to scientists' labour in these moments of infrastructure- and consensus-building. The stories of these scientists reveal to me that they feel the need to be responsive in the face of change. Responsibility has its own politics and moral economy, to be sure. And yet, what I aim to show here is why and how algal biofuels are largely embraced in Turkey.

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[149] For example, in the 1960s and 1970s, engineers became part of the leftist social movements with their own organizations. In the aftermath of the military coup d'état, by the 1980s, the politics of engineering began to be shaped by new discourses, such as "action" (*icraat*), "innovativeness" (*yenilikçilik*), "practicality" (*iş bitiricilik*) and "consensus" (*uzlaşma*) (Göle, 2012: 14).

Discover the Potential

During their presentation at the Eighth Technical Congress of Agricultural Engineering, a group of well-known scientists working on biofuels in Turkey wrote:

> Developed countries largely support R&D to spread the use of these resources [biofuels]. In our country, "renewable energy use" does not have its well-deserved place, and the required knowledge has yet to be adequately shared with society. Hence, the demand for the establishment, operation and use of renewable energy systems is not at the desired level, and this will result in missing opportunities likely to emerge in the years ahead (Acaroğlu et al., 2015: 1184) .

In this quote, a group of scientists compare the marginal place of renewables in Turkey with its prioritization in so-called "developed countries." They warn of missed opportunities if significant renewable energy investments do not materialize. Their fears are bound up with the rhetoric of Turkey "falling behind" the West. For this group of scientists, it is clear that Turkey "has the potential" to develop its biofuels sector. They note that traditional biomass energy—that is, the energy used in rural areas, e.g., burning of agricultural wastes—is "the most commonly used renewable resources" alongside hydraulic energy in Turkey (Acaroğlu et al., 2015: 1165). Furthermore, the presenters also discussed Turkey's high potential for biofuels production by introducing agricultural empirical data—for example, annual corn yields. In their presentation, I hear the suggestion that Turkey*, as an agrarian country,* has the potential to embed biofuels into its energy markets. I see this rhetoric as a form of provocation. It is provocative in the sense that it troubles dominant equations of agriculture with underdevelopment in developmentalist stories. In this section, I will examine how the rhetoric of potential has been part of the Turkish modernization process since the birth of the Republic. This analysis helps me understand how Turkish scientists' efforts to unlock "algae's potential" goes beyond their efforts to develop biofuels, and also, simultaneously potentiates a modernizing Turkey.

Anthropologist Arturo Escobar (2011) notes that, “development can be seen as a chapter…on the anthropology of modernity” (p. 277). He draws attention to the rise of development discourse in the aftermath of World War II. Escobar takes the inauguration speech of former US President Harry S. Truman (January 20, 1949) as a referential moment that signals the beginning of the age of development. Truman’s speech was the first time that, “the Southern hemisphere [was declared] as ‘underdeveloped areas’” (Sachs, 2010: xvi). The speech hailed a “new era” of global politics—particularly one that centered on the management and organization of the “less economically accomplished countries of the world” (Escobar, 2011: 269). As a result, a dichotomous representation of the world was crafted: underdeveloped versus developed countries, agrarian versus industrial economies, and traditional versus modern societies. While the former concepts are associated with supposed “backwardness,” the latter ones denote so-called “advancement.”

Scholars’ critiques of these dual representations have helped me understand how agriculture has figured Turkey’s potential for industrialization rather than signaling its “backwardness.[150] These critiques have demonstrated how “backward” representations legitimize and consolidate governmental as well as economic power over countries through the rubric of development—a process often attained through urbanization, industrialization, and technological advancements (e.g., Mitchell, 2000). Further, this literature critiques development as a framework that further divides the world in binaries of “haves” and “have-nots.” For example, political theorist Timothy Mitchell (2000) has argued:

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[150] I draw attention here to how critical scholarship on developmentalism still draws on the temporality of the so-called Western countries; it treats the aftermath of the World War II up until the 1980s as “the chapter of development in the story of modernization.” My aim is not to neglect the peculiarity of the world in the post-war era. Rather, I want emphasize how the common periodization of developmentalism—beginning with the 1940s—is likely to render the initial promotion of biodiesels in Turkey invisible. The Turkish modernizers adopted biodiesel production as part of national developmentalist efforts by the 1930s.

> [t]he production of modernity, the hegemony of the modern over what it displaces as "traditional" is never complete. As a result, modernizing forces continuously reappropriate elements that have been categorized as non-modern, such as religious elements, in order to produce their own effectiveness (p. xviii) .[151]

By highlighting the activation of non-modern elements in the modernization process, Mitchell troubles the dichotomy between "tradition" and "modern," and thus the idea of linear progress. He draws on Moroccan author Driss Chraïbi's (1954) novel *The Simple Past* to further elaborate this point. Mitchell remarks that there is a "'thin line' between tradition and modernity, the interstitial space that marks the cut or break between two, neither disavowing one nor wholly located in the other" (Mitchell, 2000: xxi). Building on Mitchell, I see how scientists' potentiation of biofuels is made possible through visions of Turkey as an interstitial nation, that is, one that lies between agrarian and industrial development, and between the East and the West.

In what follows, I outline Turkey as an interstitial space and show how the rhetoric of potential is activated within it. To do so, I will first unpack the dichotomy of agrarian and industrial countries through the case of early biofuel development efforts. Second, I explore the dichotomy of East and West through a recent branding initiative launched by the Turkish government. These exemplary cases demonstrate that the rhetoric of potential has always been deeply entangled with the Turkish modernization process since the founding of the Republic.

I first turn my attention to the development of biodiesel. It is through this example that I will demonstrate how industry and agriculture have informed the co-modernization of biofuels and of Turkey. Attempts to produce biofuels have actively participated in the Turkish

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[151] For a further investigation on the appropriation of religious elements in the modernity discourses, see Asad, 1993.

modernization project since the founding of the Republic.[152] One notable example is a report entitled, "The Use of Vegetable Oil in Agricultural Tractors," which emerged out of the 1931 Congress of Agriculture. The study was implemented at the Atatürk Forest Farm, which today is home to the controversial Presidential Palace.[153] The Farm was constituted with the directive of Atatürk in 1925 in the West side of Ankara province to guide farmers and farming activities in Turkey. It included small agricultural farms, greenhouses, a dairy farm, brewery, leather factory, and many other units related to agriculture and husbandry. Beyond promotion as a field of production, the Farm also included restaurants, clubs (*gazino*), parks, a beach, among other entertainment and recreational infrastructures.[154] The implementation of these initial biodiesel studies at the Farm has a symbolic importance; they are illustrative of the ways in which political, material, technical, economic, and sociocultural modernization efforts went in hand in hand with a nascent Republic. Put differently, it also depicts the Turkish modernization as a technoscientific process.

These earlier biodiesel projects implemented in the Atatürk Forest Farm aimed to support agricultural production by fueling tractors, and, with it, the industrialization of the country.[155]

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[152] The issue of biodiesel appeared for the first time on the Turkish state's agenda during the Congress of Agriculture held in 1931. The National Economy and Savings Society (Milli Iktisat ve Tasarruf Cemiyeti) convened this congress following its establishment in 1929. The aim of the Society was "to educate and encourage the people 'to live economically, to combat waste, and to use national products'" (Bozdoğan, 2001: 137). The Society and congress illustrate the shape of earlier modernization attempts in Turkey.

[153] Presidential Palace has been built inside Ataturk Forest Farm, and unveiled by the President Recep Tayyip Erdoğan. The Palace is widely nicknamed as the "Kaçak Saray" (Illegal Palace): Although the Turkey's Council of State ruled that the construction of the palace should be halted in 2015, the palace was already completed in the previous year. In addition to the legality issue, the opposition has criticized the high cost of the construction of the palace. Some consider this palace "as evidence of Erdoğan's autocratic tendencies" ("Turkey's new presidential palace unveiled," 2014).

[154] For further information on Atatürk Forest Farm, for example, see Atak & Şahin, 2004.

[155] These earlier studies did not last long. Although these projects later reappeared during the preparation of the Second Development Plan in 1936, World War II halted the implementation of this development plan. Nevertheless, "certain amounts of biofuels were supplemented to the vehicles used in the Turkish Army in 1942" (Aytav & Koçar, 2013: 341).

From this perspective, it is clear that Turkish modernizing elites did not necessarily perceive being an agricultural country as a sign of backwardness. Rather, agriculture became central to their industrial nation-building project. It reflected both nationalized Westernization and pragmatic modernization. At the time, agriculture was synonymous with Turkey; it was the spirit of the country. More, it was activated in pragmatic terms trough the utilization of "available resources." Likewise, contemporary scientists' stories about Turkey as an agrarian country do not connote backwardness. Rather, like earlier modernizing elites, these scientists see agriculture's potential for modernizing, industrializing, biofuels. This mode of thinking aligns with how Turkey locates itself as both an industrial and agrarian country.

I now turn my attention my second example—a recently launched branding program by the Turkish state with the slogan "Turkey, Discover the Potential." I find it illustrative to see how the rhetoric of potential is activated with the vision of Turkey in between East and West. Also, it is good to think with to underline that the contemporary modernization process should be treated differently than the earlier years of the Republic, when "Turkey turned its face to the West," as a common saying in Turkey. The branding program carries a particular message: "We are both East and West; New Turkey writes its new story."

The branding program's slogan is one of remarkable optimism: "Turkey: Discover the Potential." By drawing on the themes of discovery and potential, the slogan naturalizes Turkey's capacity for growth at the same time as it positions the nation-state as a powerful player on the world stage. Rather than merely signaling that which has yet to come, *potentiality* also recalls the past—the slogan activates the past motifs of Turkish culture to naturalize Turkey's *already existing* potential in the modernization process.

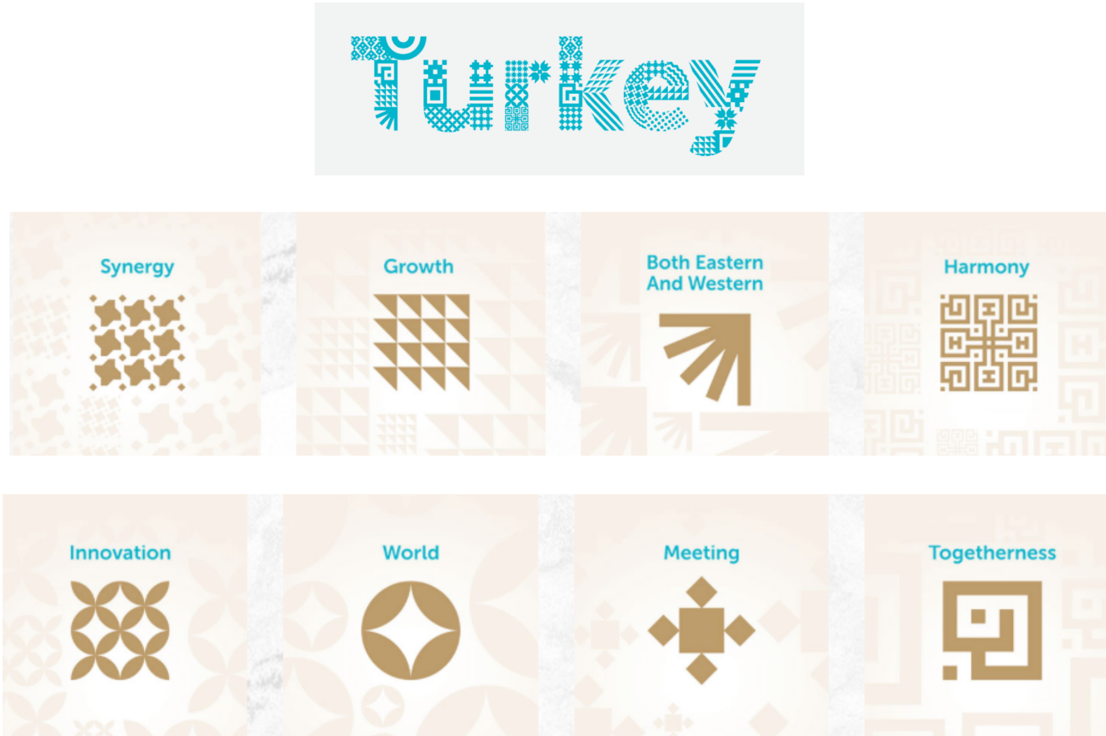

Figure 13 Imaginaries of Turkey
Snapshots from the web-site of the branding program.[156] Each motif represents a particular imaginary of Turkey.

The logo's traditional motifs visualize how the past is activated through state propaganda. Kufic script and Kilim rugs are the inspiration for the graphic elements that form and inform the logo (Figure 13s). The branding program's website provides a history of Kufic script and notes that its aesthetics, promoting simplicity and sophistication with its form of contrast and depth, represents Turkey as "a country harmonizing many contrasting layers."[157]

By referencing the past, the project evokes Turkey's rich artistic history—one that was imitated by Westerners.[158] Yet, what is at stake here is not simply a question of aesthetics—it is the *aestheticization* of potential. Similar to Walter Benjamin's (2008) critique on the aestheticization of politics, art in the logo is functionalized to "establish evidence" (p. 220).

[156] "Turkey, Discover the Potential"-Reading the brand. (2014).
[157] Ibid.
[158] The references to Islam and the Qur'an in the quote go beyond the scope of this research and ask for different interpretations of logo design, which are not subject to the phenomenon under investigation here.

Mahir Ünal, who served as the Minister of Culture and Tourism at the time when the branding program was launched, reasoned that: “[w]e need to express ourselves well; we need to change how we are perceived by others” (Güler, 2015). The state’s goal was to challenge popular conceptions of Turkey. In this sense, the use of traditional motifs should be interpreted as an act against representations of Turkey through the gaze of hegemonic power. As the use of Kilim rug designs shows, representations are performative in the sense of creating top-down economic and cultural values.

Kilim—a flat-woven tapestry carpet—constitutes the other inspiration for the logo’s design. The branding program does not provide any explanation regarding the selection of kilim rugs, unlike for Kufic calligraphy. Through anthropologist Kimberly Hart’s (2006, 2011) ethnography of kilim weaving and trade in an Anatolian village in Turkey, it seems that the use of kilim motifs in the logo revitalizes “tradition.” In conversation with Michael Herzfeld’s (2003) ethnographic work in Greece, Hart approaches tradition “not as a conscious or literal enactment of the past, but rather as a component of political ideology against which ideas of modernity are conceptualized and within which people and things are compartmentalized in a global hierarchy of value” (Hart, 2006: 17). Accordingly, she claims that, “carpets have value insofar as they are labeled as being ‘traditional’” (ibid: 18). Thus, labeling something traditional is not all about cultural values, but also about how economic value is created from things represented as traditional. Such economic value generation is the overall intent of the branding program. Similar to Hart’s ethnography, I read the branding program as a modernization project that activates, vitalizes, and potentiates the past while embracing tradition. Yet, there is more in this “revitalization of the past”; the branding program potentiates Turkey’s identity as being both Eastern and Western.

The logotype embeds eight motifs in total (Figure 17); these motifs are different, yet at the same time they entangle sociotechnical imaginaries of Turkey's potential. Each motif "represent[s] a different value of rising Turkey" ("Turkey DTP Guidelines," 2015: 14). A close reading of all the motifs described on the website of the branding program is not possible here.[159] Yet, it seems that all of the motifs touch on Turkey's ethos in some form: Turkey gives "meaning" to matter, Turkey is home to the origins of world histories through its innovation and growth, and Turkey has always been part of the world and integrates diversity in harmony. Turkey is in the world, and the world is in Turkey, according to the basic message circulated by these different motifs.

Further, the motif of the *Both Eastern and Western* tile in the logo suggests that Turkey serves as a bridge in a world divided between "East" and "West." It has been home to all civilizations, diversified through the historical movements of civilization from "East" to "West." It is like the sun rising from the east and descending in the west.[160] The metaphor of the "sun" here helps us see how the performativity of motifs, which naturalize Turkey's potential for bringing together different "civilizations," works. Under the theme "Meeting," the future also unfolds such "potential."

During the launching ceremony organized by TİM in September 2014, President Erdoğan translated the slogan, which was first formulated in English into Turkish by noting that the usage of the word *güç* ("power") instead of *potansiyel* ("potential") is much more appropriate.[161] From then on, "Discover the Potential" was translated into Turkish as *Gücünü Keşfet* [Discover its Power]. As Erdoğan has noted: "We are a powerful country, and aware of our power. Actually,

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[159] "Turkey, Discover the Potential"-Reading the brand. (2014).

[160] The "rising sun" translates into Turkish as *doğan güneş*. *Doğan* is derived from *doğu*, that is, the East. Similarly, "to descend" translates as *batmak*, derived from *batı*, that is, the West.

[161] See "Türkiye logosu ve gücü keşfet sloganı, Türkiye'nin özgüveninin simgesidir," 2014.

new Turkey is Turkey discovering its power and potential. God willing, the ones who have yet to discover this power, will do so soon." The use of the term *power* instead of, or alongside, *potential* hails Taussig, Hoeyer, and Helmreich's (2013) calls to identify potential as calls for action. They see the "articulations of potential typically enact politics by working on and through morality, by making claims on us to do something" (p. S6). Accordingly, the slogan "Discover the Potential," heard in the imperative as a command, is not limited to state propaganda according to which Turkey is supposed to achieve legitimacy and power in the world, or at least in the region.

Potentiating Modernity through Algal Biofuels Research

By chance, I met Fatih face-to-face at the 7th International Energy Expo Congress held at the Congresium, Ankara. Fatih is a leading biofuels researcher working at one of the state institutes of agriculture in the Black Sea Region. Prior to our meeting, I was only acquainted with his published work. As I wandered around the congress's exhibition grounds, I struck up conversations with fellow attendees. This is how I encountered Fatih. As we spoke, I slowly came to the realization that person before me was the same researcher I had encountered in my readings. Excited to meet such an eminent biofuels researcher, I asked him whether he would be interested in talking about his work. He graciously accepted.

Although unprepared for this impromptu interview, I drew on my past conversations with other biofuels researchers for inspiration. As we sat down together, my first question for Fatih was how he cultivated interest in algal biofuels research. Smiling, Fatih recounted an impressionable moment that occurred at a symposium on oil seeds and biodiesel in 2007. He recalled a presentation on algal oil yields that drew his attention:

> There was an article that discusses how much oil can be obtained from which material. The numbers regarding algae was magnificent. Let me say, for example, you can get 150 kg of oil

> from soybeans per decare, 250 kg from rapeseed. The article says 4 to 14 tons from algae. We had not done any work on algae; it was not our area of expertise. Yet, we said, if these numbers are real, it is terrific… We thought that algae's potential is significant; it has the potential to be the future's raw material for fuel.

The numbers indicating algae's "natural potential" as a biofuel producer impressed Fatih. Despite being the only paper on algae at this conference, this presentation and its "numbers" tell us two things. First, in the span of ten years, algal biofuels have grown a marginal research area in Turkey to one of great potential. Second, it demonstrates how "numbers" can potentiate not only algae, but researchers themselves.

Fatih told me that immediately after the 2007 symposium, he and his co-workers contacted an associate research institute. To make the connections clear to me, Fatih explained that both organization operate under the Turkish General Directorate of Agricultural Research and Policy and answer to the Ministry of Food, Agriculture and Livestock. "To develop a project on algal biofuels," he recounted, "we talked to them." He continued: "They were to take responsibility for the cultivation of algal biomass, and we were then working on how to produce fuel via this biomass." In time, the scope of the project grew through the involvement of several aquaculture and fisheries departments from various universities. Based on this expansion, Fatih and his colleagues collaboratively worked on a proposal to receive funds from the Scientific and Technological Research Council of Turkey (TÜBİTAK). However, due to structural changes to TÜBİTAK, the team could not submit their proposal directly to the council. [162]

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[162] Previously, public researchers applied directly to TÜBİTAK in order to receive project funding. The new structural framework fundamentally altered this procedure. At the request of the Ministry of Science, Industry, and Technology, TÜBİTAK narrowed its scope of fundable projects, and, in turn, limited which researchers could apply for grants. Additionally, changes to its organizational structure also reflected a radical shift in public policy. Previously an institution under the Prime Minister's Office, in 2011, TÜBİTAK was transferred and managed by the Ministry of Science, Industry, and Technology. In this sense, TÜBİTAK shifted its priorities towards fulfilling the demands of ministries rather than individual research projects developed by public scientists.

With the support of the General Directorate of Agricultural Research and Policy, Fatih and his co-workers petitioned the Ministry of Food, Agriculture and Livestock to apply for funding from TÜBİTAK on their behalf. This strategy was meant to fund a broader call for Turkish algal biofuel project applications. The Ministry approved the request and TÜBİTAK sent out the call in 2012. It was the first time that algal biofuels officially entered the political arena in Turkey. Intriguingly, this has been the first and only call launched by TÜBİTAK upon the request of any ministry. Fatih's story was one of several that I encountered during my fieldwork in Turkey, but it was perhaps one of the most important. It was significant in three ways: first, it elucidated how scientists must to navigate political obstacles in order to conduct research. Second, it demonstrated the importance of scientists' contributions in the making of the Turkish biofuels sector. Third, it pushed me to think further about scientists' role in the making of Turkish algal biofuels. Inspired by Fatih and his colleagues, I ask: how do scientists potentiate algae as a biofuel source in Turkey?

During my fieldwork in Turkey, I encountered a variety of scientists all interested in the question of biofuel development. Some of the scientists I interviewed were specifically developing algal biofuels projects, while others were not directly invested in algae. These scientists were from diverse fields of study, ranging from environmental engineering, chemical engineering, aquatics and fisheries, as well as biology. During our interviews, each one told me how they cultivated their interest in algal biofuels, while detailing their unique experimental practices and approaches towards biofuel development. However, as I listened to how these scientists potentiated algae as a compelling energy source in Turkey, I heard another subtext arise. Underlying their stories was a narrative of how algae helped scientists modernize Turkish technoscience alongside a developing biofuels sector.

The second section of this chapter will focus on three stories. Through contrasting lenses of algal biofuels, each story provides a separate analytic for understanding the potentiation of modernity in Turkey. The first story is about the potentiation of algal biofuels research in the image of Western models. It follows an American-educated, Turkish scientist and his IMBIYOTAB project. This project is notable for being the only Turkish biofuel project recognized by the American non-governmental organization, Algal Biomass Organization (ABO).[163] The other two stories support the first. In the second story, we meet Nalan, a biologist who is alarmed by rapid changes in the Earth's climate. In "Urgency," Nalan helps us unpack temporality as a key analytic for addressing mortality and speed across difference scales. The final story turns attention towards obscure algal biofuel projects, Turkish scientific ingenuity and what it means to be a Turk. Common to each story is that when algae are potentiated in bioeconomies, the Turkish bioeconomy is modernized.

Modeling

In 2015, Berat Z. Haznedaroğlu, an assistant professor at the Institute of Environmental Sciences at Boğaziçi University (Istanbul), launched the İstanbul Microalgae Biotechnologies Research and Development Center (IMBIYOTAB) project. This was the first, large-scale pilot project related to algal biofuels in Turkey. Further, it is the only Turkish project recognized by the Algal Biomass Organization (ABO), an American non-governmental organization. Considering that Haznedaroğlu undertook his post-graduate studies in the United States and built networks there, this Turkish-American connection is not a coincidence. Based on participant-observation conducted in biofuels seminars alongside my conversations with Haznedaroğlu, I realized that IMBIYOTAB is a product of nationalized Westernization. In this section, I explore how

[163] Strikingly, the IMBIYOTAB project is the only Turkish one to appear on the ABO's online map of companies and research activities related to algal biofuels worldwide.

Haznedaroğlu's design and promotion of IMBIYOTAB potentiates algal biofuels in Turkey in a way that reproduces a form of nationalized Westernization. I argue that this form of potentiation is indicative of neoliberal development.

The IMBIYOTAB project began with funding from the Istanbul Development Agency under the Innovative Actions Program. Several academics from Boğaziçi University, İstanbul Medeniyet University, and Yıldız Technical University coordinated the project, which also included several private sector partners. The project was housed on Boğaziçi University's Sarıtepe Campus in Kilyos, located on the Black Sea coast of the European side of Istanbul.[164] Sarıtepe is notable for its reputation as a "sustainable green campus." During the project's first seminar series, Haznedaroğlu stated that this pilot project would utilize approximately $100m^2$ of land and $250m^2$ of sea, in addition to the already-existing wind power available on the campus. In short, the project was planned as a net-carbon-negative facility. From this vantage point, one could state that the desire for "sustainability" potentiated this project. Yet, as I underscored in the previous chapter, sustainability itself is potentiated through the design and engineering of algal biofuels projects. What sustainability means to scholars like Haznedaroğlu? How does it get potentiated through the design of IMBIYOTAB project? And, what can it teach us about the way sustainability unfolds in Turkish algal biofuels projects?

The IMBIYOTAB project adopts a certain approach—the biorefinery; that is, the integration of multiple industries that use algae as biomass in the production of, for example, pharmaceuticals, cosmetics, fuels, and food additives. The biorefinery creates revenues and profits at different scales of algal biofuel production. It does so through collaborations among divergent industrial sectors. For example, during a pilot-scale algal biofuel project, a company

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[164] See website: https://imbiyotab.boun.edu.tr

may, in collaboration with other firms, produce additional commodities from algal biomass. Revenue is then generated through the sale of these high-value products, which may include pharmaceutical chemicals. Quite simply, the biorefinery approach espouses cost-efficient algal biofuels production while advocating the use of algae in different sectors from energy to medicine. I learned more about this approach from Murat Elibol, a professor in the Department of Bioengineering at Ege University.[165] In a presentation at the Istanbul seminar, Elibol projected a slide that read: "Year 2016, still…only a few commercial-scale production plants are using algae as a feedstock for fuel." Notably, the ensuing slide listed several American companies in the business of algal biofuels: Solazyme, Sapphire, Joule, Algenol, and Cellana. Elibol ended his talk by claiming that a biorefinery approach can overcome impediments to a commercial-scale production of algal biofuels in Turkey.

During Elibol's presentation, my attention was drawn to one of his slides: "*High-value coproducts*, such as nutritional supplements, currently the main commercial microalgal products, *are not of interest in large-scale biofuels production,* as their markets are too small to be relevant" (emphasis in the original). As he paused on this slide, Elibol explained to his audience why American companies do not seem willing to adopt a biorefinery model. He argued that the United States is much more interested in large-scale algal biofuels production in order to replace dependent fossil fuel economies. However, he noted that was not the case in Turkey. Instead, Elibol sees the biorefinery model as better suited to the "Turkish reality" of smaller markets. He sees the biorefinery as a creator of new markets in a country where economic growth is of utmost importance. This emphasis on Turkish realties is also present in IMBIYOTAB's brochure:

> *An expert in its field, a special facility for Turkey*: The Microalgae R&D unit was established as a solution to Turkey's three major problems—namely, food, energy, and water—in the 21st

[165] "Biofuels from Microalgae and Bioenergy Applications" (June 27, 2016).

> century, with an eye to sustainability…This unit conducts research in order to decrease Turkey's external dependence, by producing knowledge and high technology for all related institutions, primarily public and private ones, operating in the food, water and energy sectors.

This quote highlights the discursive field of algal biotechnology transfer in Turkey. The brochure spells out the twofold aim of the IMBIYOTAB project: (1) to find a solution to Turkey's three major problems of food, energy, and water; and (2) to decrease Turkey's external dependence. The latter aim highlights the desire for independence as the heart of the Turkish modernization process. The former aim reframes the question of dependency in terms of the food-water-energy problem—a claim that echoes Jonathan Trent's vision of the OMEGA project (See Chapter 3). Both the IMBIYOTAB and OMEGA projects claim algae as a sustainable technology that has the potential to solve this problem.[166]

It is not a coincidence that Haznedaroğlu's IMBIYOTAB project shares similarities with Trent's OMEGA project. As a Turkish-born, American-educated scholar, Haznedaroğlu straddles the divide between both intellectual communities.[167] Notably, by the time Haznedaroğlu returned to Turkey after being awarded a position at Boğaziçi University, he had already gained expertise abroad in microalgal technologies and had spent several years following developments in the US algal biofuels sector. Hence, Haznedaroğlu's encounters with the West have already informed his Turkish-based project. His emphasis on and sensibilities towards Turkey's problems of "food, water and energy" should be interpreted in light of these encounters.

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[166] Also, Haznedaroğlu, in his introduction to the first seminar series entitled "Microalgal Biomass for Water Quality and Wastewater Treatment" (May 30, 2016), noted that algae are valuable at the nexus of food, water and energy, and announced the upcoming "International Conference on Microalgal Technologies at the Food:Water:Energy Nexus" in September 2016 at Boğaziçi University.

[167] Having received his bachelor degree in biology from the Middle East Technical University in 2003, Haznedaroğlu completed his post-graduate studies in the United States. He was awarded his M.S. degree in the civil and environmental engineering program at Villanova University and his PhD in the same program at the University of California-Riverside. Haznedaroğlu began working on microalgae technology during his postdoctoral studies in the Chemical and Environmental Engineering Department at Yale University and completed them in 2012.

Given the similarities between the IMBIYOTAB and OMEGA projects, one could argue that Haznedaroğlu promotes his project through rising trends in the American life sciences. Following Sunder Rajan's (2006) study of the bioeconomy in the making in non-Western countries—particularly, in India—I note that the IMBIYOTAB project follows a distinctly American model. Put differently, Haznedaroğlu fashions his project by importing Western concepts of algal biotechnology into a Turkish context. However, this assumption oversimplifies the desire for "external independence" by rendering the adoption of a biorefinery approach invisible. Haznedaroğlu's reframing and redesigning of his project to fit "Turkey's realities" should be taken into account. From this vantage point, I suggest that Haznedaroğlu potentiates algal biofuels through a form of nationalized Westernization, which emphasizes Turkey's need to grow markets.

This point became more apparent as I listened to the stories of other algal biofuels scientists. Projects in Turkey do not solely focus on producing biofuels from algae. They either integrate biofuels production with bioremediation processes (e.g., the case of Demirer's project), or they potentiate algal biofuels combined with the production of other products, such cosmetics, and pharmaceuticals. Further investigation into these concerns is beyond the scope of this dissertation. Nevertheless, I see the potentiation of algae into multiple consumer products and technologies in the Turkish context is related to its nationalized Westernization. In this sense, algae's potentiation highlights the Turkish government's growth-oriented economic policies that look for "opportunities" to create new markets. This is but one story of how neoliberalization unfolds in Turkey (also, see Türem, 2011).

Haznedaroğlu's project taught me how powerful Western imaginaries potentiate of algal biofuels in Turkey. Rather relying on the trope of "modeling the West," I suggested to unpack the historical contexts of nationalized Westernization in Turkey—contexts that have both potentiated and materialized the modernization process. In the next section, I will turn to the story of a Turkish scientist that teaches about another rhetoric of modernity, one that could be called, "belatedness."

Urgency

November 2014, Phytoplankton Lab in a small university campus located in a coastal town in Southeastern Turkey. On the table in front of me sat a rectangular plastic basin. One third of it was filled with water. Floating inside was a strain of macro-algae, ready to be "isolated."[168] I, too, was also ready—holding tweezers aloft in my right hand as I waited to fish out these life forms. Scooping my gloved left hand into the basin, I pulled out a delicate strand with three fingers, cradling the algae carefully with the help of a fourth. Each time I touched the algae with the tweezers, my body inched closer to the table and my head drooped forward. Every other minute, I sat up, straightening my spine before doubling over once again. My body could only bear such work for fifteen minutes at a time—this, despite my excitement for seeing new worlds unfurl with each of movement of the tweezers. I was assisting Nalan, a biologist working on algae in the Faculty of Fisheries and Aquaculture, while chatting with her about algal biofuels research in Turkey.

A tape recorder rested on the table before us. I asked Nalan questions about the details of her experiment on the potential usages of algae for human consumption, such as cosmetic products, fertilizers, and fuels. The more passionately Nalan spoke of algae, the more excited I became about algal life. Our conversation, however, came to an abrupt halt when she told me:

> In the country where you live, in the West, what we experience now has already been experienced: the industrial revolution ended, everything is routinized, and biologists and the

[168] Isolating algae refers to the process of locating a "foreign" body that needed to be removed.

> nature that they have lost are now more important. We are at the beginning of this process; here, everything is interrupted, and nothing is stable.

Listening back to the recording, I can hear my voice murmur into the tape recorder: “These sound like clichés to me.” I had bristled at her insistence that the West and Turkey operated on a linear timeframe—that is to say, I rejected the notion of unilineal progress and the suggestion that somehow Turkey was behind on the time line.[169] Nalan heard me and turned her face to the table where I was sitting. In a single sentence, she remarked matter-of-factly: “Duygu, this is how our life here is!” Even now, I can envision the punctuated exclamation mark dangling at the end of her sentence. She smiled.

Our exchange made me think about the labour that goes into working with algae. In her rush to cultivate algae, Nalan is also crafting a story about Turkey. When she uses the rhetoric that Turkey needs to “catch-up with the West”—is she suggesting that “progress” is linear. However, the more I listened to Nalan’s story, the more I realized that it was important to understand how this rhetoric gets formed in the context of algal biofuels. In this section, I will explore how Nalan’s sense of urgency speaks to different timescales of nationhood and algal growth as it simultaneously potentiates her own passion and concern for algae.

Twice a year, Nalan spends two to three weeks on the coast collecting *deniz yosunu* [macro algae] for her new project. She carries strains collected from Iskenderun Bay to her Phytoplankton Laboratory with the help of temperature-sensitive cooler bags that she borrows from her colleague. The diminutive size of her lab reflects the small size of the Faculty of

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[169] Linear time—clock time, or what Walter Benjamin calls “homogenous empty time”—is the dominant conception of time in modern societies (cf. Thompson, 1967). The perception of time as linear is associated with the rise of capitalism (Firth & Robinson, 2014). I refer to the conception of linear time embedded in the idea of progress and development within the terms of modernity. There is a broad literature that sheds light on the relation between modernity and time (for example, see Adam, 1998; Bauman, 2000; Bhabha, 1991; Giddens, 2013; Nowotny, 1996). The conversation with this literature goes beyond the scope of my research. Rather, I put emphasis on Nalan’s perception of time to show how Turkish scientists reclaim their work *always* in reference to the West.

Aquaculture building; the lab is a scant nine square meters. Furnished with shelves, a microwave, a precision balance scale, and a sink, the Phytoplankton lab resembles more of a kitchen than a laboratory. Indeed, at the centre of the room stands a table, surrounded by four stools, and piled high with plastic cups, tags, and a number of rectangular plastic basins for good measure. Yet, there is no refrigerator in sight; it seems impossible for a standard-sized appliance to fit into this room.

As she went about her daily lab work, Nalan travels back and forth several times to the room next door. She does so in order to retrieve packages of frozen algal strains from the refrigerator collectively used by faculty members and students. As I continued working with my tweezers, I listened to her complaints about the inadequacy her lab equipment—tweezers, for Nalan, cannot compare to proper forceps. Indeed, these missing tools were a source of much frustration. When Nalan returned from maternity leave, only a small number of her lab tools had survived her absence. She confided in me that it would take a long time to restock the lab with the materials needed to carry out her current project. Nalan was anxious; she believed that there was not enough time to realize the projects she envisioned.

Nalan feels that "geological time" is running out as we speed through the twenty-first century. Nalan was looking for a way to counteract this acceleration. She told me that algae might help "slow down" rampant geological changes, including the melting of the polar ice caps. She attributed algae's potential for "catching up" to the accelerations of geological time to their rapid growth rates. As fast-growing organisms, Nalan believed that algae have the potential to keep up with the rising volumes of atmospheric carbon dioxide by absorbing these gases into their growing bodies. "If it takes 80 years for a forest to grow, we can generate a forest with microalgae in a month," Nalan exclaimed excitedly. For Nalan, these fast-growth algal forests could help humans both keep pace with the speed of geological time and slow it down. It should be noted that algal researchers think of algae as timekeepers. They are renowned for their ability to slow down human aging. This is evidenced in the proliferation of anti-aging substances and nutritional supplements in personal care and wellbeing markets. Still, what motivates and excites Nalan to work with algae is their "natural potential" to reverse both human and terrestrial aging. In Nalan's hands, algae's potential is naturalized through her perceptions of time.

Nalan's stories of what she calls "phytoplankton time" also made me worry about time. Dusk had already fallen. The clock on the wall indicated that it was 5 p.m.; I glanced over to Nalan to see whether she was ready to pick up her child from the daycare center. Instead, I found her sitting at the table, in deep concentration. Methodically, she continued measuring "isolated" macro algae strains, putting them into plastic cups, and labeling them. I then looked at my watch: it showed 4 p.m. The wall clock was wrong, I surmised—it had not been adjusted to account for daylight savings time. Pondering this curiosity, I reflected on the nature of temporality. I ask: *how is a sense of urgency over accelerating global warming linked to a feeling of "belatedness" that comes with living in a country that needs to catch-up with the West?*

Nalan's sense of urgency is about catching up not only with geological time, but also with Turkey's modernization. As previously noted, novelist Atay's interpretation of scientists' attitudes during the establishment of the Turkish Republic can elucidate this feeling. Scientists at that time had a sense of urgency to learn about "everything" as a response in the face of newness. I argue that a similar sentiment is behind Nalan's sense of urgency—that is, Nalan's response is a reaction against change. As algae get temporalized in the hands of Nalan, she herself is potentiated alongside algae as a pacemaker for Turkey's modernization.[170]

Obscured

To my surprise, I unexpectedly came across several researchers designing and building systems related to algal biofuels during fieldwork in Turkey. These encounters were unexpected because these researchers did not have a prominent public presence. They did not publish articles, nor did they present their findings at conferences. Strikingly, their names did not even come up in my conversations with other scientists. They were, for all intents and purposes "off-the-map" of biofuels development. I learned of their "secret" projects by chance—it was usually as I was interviewing these interlocutors on other subject matters. Towards the end of our conversations, scientists would often ask me to stop recording before telling me of their side-projects.[171]

In this section, I will tell the story of marginalized scientists who engineer algal biofuel production systems out of their own volition, and at their expense—often eschewing state recognition and private sector funding in the process. More surprisingly, several of these scientists did not have formal engineering backgrounds, but instead designed and built infrastructures, such as photobioreactors, based on their interests in algal biomass cultivation. Why would they do this? What new insights does this story say about the potentiation of algal biofuel projects in Turkey?

I learned that these scientists' desire for confidentiality reveals different concerns. Notably, several scientists are afraid of plagiarism and, as such, do not publish their research.

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[170] Here, we can also juxtapose Nalan's sense of urgency with Chisholm's feeling of responsibility (Chapter Two). This attempt goes beyond the scope of this chapter, about which I want to continue thinking as part of my future projects.

[171] I note these requests to underscore how concerned scientists were with keeping the specificity of their projects under wraps.

Fear of plagiarism is common in Turkish academia. Rather than investigating plagiarism as a practice, I am drawn to the affective dimension of this phenomenon. The scientists I had spoken had expressed concerns that their work was not recognized at the experimental stages. These same scientists were frustrated by what some would see as structural barriers to their work. I found that many of theses scientists conducted their projects outside university laboratories and financed their projects without assistance from well-known institutions, such as TÜBİTAK.

Furthermore, these researchers expressed a desire to maintain their own prestige. They were afraid of making mistakes and of the associated stigmatization of being seen as "incompetent." More, they were concerned that their failures could be interpreted as failures of their country. For me, this fear of failure is also related to the novelist Atay's concept, "knowing about everything." It seems as if these researchers have grown up in a culture that propagates something that could be called "Turkish intelligence," or the idea that Turks have the "potential" to do anything they set their minds to. Thus, if researchers feel incompetent, it is not only an individual failing, but also failing the state. In other words, scientists feared falling short of the expectations demanded of being a "Turkish scientist"—scientists, in turn, who are responsible for modernizing Turkey. From this vantage point, it becomes clear that, similar to Nalan's sense of urgency as a generalized feeling, this sense of failure is also internalized—it is an affect that is experienced through the modernization of Turkey.

Although these small-scale, indiscernible projects may be thought of in terms of do-it-yourself (DIY) projects—since they do not require funding and depend on the creativity, labour, and endeavors of their builders—their opacity obscures how Turkish scientists were, and are, supposed to build a modern Turkey. In other words, scientists are expected to "fight [on] many fronts," in Atay's words, in order to contribute to a modern Turkish nation-building project—a nationalist effort, that includes infrastructure building, educating people, among other institutional facets.[172]

In short, focusing on these purposefully obscured algal biofuel projects draws attention to the politics of recognition and confidence in the ways that scientists fashion themselves. As such, these scientists learn to envision themselves as tenacious and as capable of carrying out their projects despite hardships. My sense is that the desire *to be recognized* and the feeling of *self-confidence* have roots in the Turkish experience of modernity. As Bora emphasizes (2017), Turkey has presented itself as an unencumbered, energetic and youthful nation in comparison to Europe's sordid past of exploitative imperialism, colonization, and the darkness of the mediaeval times (p. 92). The claim for Turkey's newness not only reflects the desire to be recognized on the same level as the West, but also, the ideal of being more Western than the West—a concept that Bora calls, "extra-Westernism."

Extra-Westernism stands at the core of building national self-confidence in Turkey. Its presence dominated the Republic's nascent years, and continually shapes the contemporary political environment in Turkey under the rule of the JDP Government.[173] For Bora, extra-Westernism is about extra-modernization—that is, it claims it has the potential to renew and develop modernity (Bora, 2017: 92-93). In this regard, it is possible to see that researchers developing algal biofuel projects out of view of the public gaze and through their own means do so with a similar belief. In other words, these scientists believe in their personal capacity to succeed, despite deficient funds or other intellectual infrastructures needed to do research. As

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[172] Perhaps more than DIY project, these small scale projects can be thought in relation to the culture of apprenticeship, which simply suggests learning by doing alongside an *usta* (master). It is about learning about everything that is related to what one is making and/or working on. For STS literature on apprenticeship, for example, see Gusterson, 1998; Kaiser, 2009; Myers, 2015.

[173] The Justice and Development Party (Adalet ve Kalknma Partisi-AKP) is a liberal-conservative party that was founded in 2001. The JDP has continuously governed Turkey since 2002.

one biofuel scientist one told me, “it is not important that the university does not let me use the labs, my lab is in my mind and heart.” I read this as a form of pragmatic modernization.

The story of the marginalized scientists sheds light on how engineering culture potentiates algal biofuels in Turkey. As I earlier alluded to in this chapter, engineering is not simply a technical matter, but a cultural practice of modernizing Turkey. I argue that the rhetoric of failure is deeply embedded in Turkish culture as it is activated through the politics of recognition and self-confidence that signals extra-Westernism. Without exploring engineering culture in Turkey, it is difficult to grasp why scientists would embrace algal biofuels as a “timely” phenomenon despite of the claims for its “untimeliness.” Lastly, from this vantage point, it is also possible to see how the rhetoric of potential unfolds in and through engineering culture in Turkey—this understanding elucidates the relations between Turkish scientists’ potentiation of algal biofuels and the Turkish state’s claim to be a powerful country. To conclude this account, I turn now to the conclusion of this dissertation.

Conclusion

Stories of algae tell us much about the world and ourselves. When I think about how my Turkish interlocutors came to embrace algae, I reconsider my own motivations for studying the cultures of algal biofuels. I raise this question not only as a self-reflexive practice, or to draw attention to my own situatedness as both a Turkish citizen and student of STS. Rather, I also want to bring home some reflections on what it means to work with more-than-human others inside of Turkish modernization projects.

Something special happened during my fieldwork in Turkey that differed from my experiences in the United States. I learned that I was doing *interesting* research. What does this mean? What is of interest, to whom, and when? To my interlocutors, the research that led to this dissertation was something new and exciting. Whenever I found myself explaining my anthropological and STS approach to the study of algal biofuels, I was met with a palpable curiosity. "This *is* interesting," was a refrain I heard again and again. I read these responses as something telling about Turkish interest in STS as a field of study. In Turkey, STS research is not well established. This is strikingly different from my experiences in the United States. When I juxtaposed my fieldwork in Turkey with conversations I had with Penny Chisholm, what became clear was that unlike my Turkish interlocutors, Chisholm was already familiar with STS scholarship when we met. But this wasn't the whole story. I realized that I was assuming that Turkish scholars were finding the newness of STS to be *interesting*. I had to ask myself why I thought this way. I discovered that this assumption hinged on the idea that what is new is always interesting or promising. As I would later learn, this is most certainly not a universal belief, nor was interest the only response to my research.

Indeed, some people found my work on algal biofuels in the Turkish context to be irrelevant. According to these interlocutors, algal biofuels are not an issue in Turkey. I was frustrated that I could not convince them of the importance of my research. In these moments, I reflected back on my conversations with environmental activists in Turkey. Though these conversations with activists were not prominent in stories I told in the preceding chapters, these encounters did shape my ethnographic understanding of the field. Unable to articulate my own half-formed responses to these activists' provocations, I often found myself agreeing with them about that algal biofuels are secondary to many other urgent political ecological concerns. It was only during the writing process that I began to understand that the ways that people try to convince one another about the merits of biofuels research is itself part of the potentiation process. This helped me see that my project was really about politics of algal research, and the politics of potentiation more broadly.

I want to approach these thoughts, assumptions, and responses as differing modes of attention. It is of utmost importance to understand how and why people get drawn towards certain things of interest and not others. For me, this is how ethnography begins. What I have learned is that one becomes an ethnographer through the process of learning how to be attentive to others. Ethnography is about cultivating different modes of attention. This is what I learned from fieldwork and the writing process. As I cultivated my sensibilities as an ethnographer, I slowly learned about the politics of my research. I discovered what was compelling and convincing about the cultures of algal biofuels, and what would activate researchers. I learned what is involved in the work of potentiation. Potentiation, I learned, is about activation. It is about how we activate things, and to what end. In what follows, I will revisit discussions from each chapter to ask: what forms of potentiation did I observe during fieldwork, and what did I want to potentiate in my own analysis?

Chapter Two began with a simple question: why algae? When I listened to how scientists, governments, corporations, analysts, and bloggers made promises about algae's potential to improve our lives and for the planet, I thought it was a marketing gimmick. And it is. However, these promises definitely convinced people of algae's potential. Scientists were invested in algal biofuels. I wanted to understand this investment. I also wanted to learn how scientists themselves also become potentiated through what and how they potentiate. In our conversations together, I learned that these scientists believed in a sustainable energy future based on algae, they were convinced about it, and they were excited about it. Why? When I asked them how they began working with algae, what I learned was surprising. In their stories, my interlocutors got me questioning not only *how* they started working with algae, but also *why*. For many, their *interest* was their answer. Afterwards, I began to see that life scientists potentiate algae in a way that makes algae compelling for them. I asked: how do life scientists stage algae's potential in a way that "algae's economic potential" is taken natural, innate? To investigate this question, *photosynthesis* became a central focus. Stories about algae's greatness are always refer to its "photosynthetic potential," in one way or another.

This chapter was divided into two halves. In the first section, I focused on evolutionary stories to understand scientists' participation in algae's potentiation. I wanted to unravel the narrative threads woven through evolutionary stories of algae. These stories suggest that: fossil fuels are made of algae, algae are ancient aggregated energetic life forms, and that, inside their bodies, algae hold together stories of pasts and futures. Alongside Chisholm, I documented the ways that scientists tell stories about *algae's ecological roles* to potentiate algae as labouring organisms for productive ecologies. I drew attention to researchers' use of machinic metaphors inside of this potentiation process. These mechanized, evolutionary stories not only tell us how algae are ecologically important, but they also potentiate algae in terms of their functions in global ecological cycles. This was how algae became visible to Chisholm, and helps to explain why she feels responsible for learning more about algal lives.

In the second section, I focused on laboratory experiments, and how scientists cultivate algal biomass. Alongside Mira, I learned how to "grow" algae. She thought this hands-on experience would be important for my research. It was, but not in the way she had anticipated. As I participated in growing algae inside of test tubes (*built ecologies*), I observed how scientists like Mira are also growing algal cultures. In their experiments, algae are rendered into a *resource* even before it gets to market. More precisely, algae are potentiated as a resource in the life sciences by being activated as: (1) compelling organisms inside of evolutionary stories, and (2) as productive organisms through scientists' interventions, techniques, and devices.

Second, I turned to another Turkish life scientist and his research on algal biofuels. Alongside Kavaklı, I learned that parameters, such as light, were not only conditions for growing algae. Instead, these parameters also had the "potential" to be manipulated, rendered, and made *efficient*. Through light experiments with algae, I learned that scientists were trying to go beyond the "limits to efficiency." When scientists potentiate algae as biomass for biofuels production, they are simultaneously potentiating the vision of efficiency as a goal. This can be achieved even with non-photosynthetic algae, where photosynthesis becomes dispensable. Through this economization, algae are reduced mere carbon sources. Efficiency and what it does to the world demands further analysis. Extensive work has been done on the question of efficiency in relation to industrial modes of production. Despite this work, I am more intrigued by the ways in which life becomes reduced to terms of efficiency, where efficiency is potentiated as an indispensable part of sustainability.

The third chapter explored how sustainability is made. My main object of study was *integrated systems.* I examined two research projects, one designed by environmental engineer Göksel Demirer in Turkey, the other project by NASA scientist Jonathan Trent in the United States. The commonalities between these projects were their integration of wastewater treatment and carbon dioxide absorption with algal biofuels production. An analysis of these production systems was helpful in order to see how algae are potentiated as sustainable energy resources. I challenged the naturalization of algal photosynthesis as inherently sustainable. Instead, I demonstrated that sustainability is designed and engineered, and itself in-the-making in these projects.

In the first section of this chapter, I explored how certain sustainability imaginaries get potentiated, enrolled in, and are made possible through integrated systems design. I treated sustainability as the material-semiotic-affective conditions of possibility for practitioners to put together integrated-wastewater treatment systems, carbon absorption, and energy production processes. I flagged the discursive practices around *excess* and *endurance.* I then explored how sustainability is integrated, constrained, and contained into systems of production. I demonstrated how *cultivating algae is made sustainable* by tracing how “pollutants,” the chemical elements, get inside and out of built ecologies. I drew attention to how algal cultivation depends on the framing of industrial waste and pollutants as externalities. I recognized that the driving force behind these integrated systems were environmental problems. Importantly, I saw that these problems were potentiated as *opportunities* in order to cultivate more algae and produce fuels. And I showed that when algae are potentiated through these systems, environmental problems are rendered invisible under the guise of sustainability.

Sustainability, as I argued in this chapter, meant making resources. In other words, it meant potentiating environmental problems as opportunities for efficient production of algal biofuels. This is another form of economization. My interlocutors talked about it in terms of "waste valorization." What was interesting for me was what designers of these systems were expecting from them. While Demirer was more interested in the idea of waste valorization, Trent was interested in what waste was doing. Although it was not possible for me to deeply engage with these different perceptions of waste, they do tell us something about the cultural forms that shape expectations of algal biofuels differently in the cultures of science and engineering. When I take into consideration how industries get modeled as integrated systems through different expectations, I think about what this means for future studies in STS.

The last chapter centered on Turkish algal biofuels. My fieldwork at home revealed new questions about algal biofuels beyond economization processes. My interlocutors in Turkey told me other stories worth listening to. By focusing on engineering culture as more than a techno-managerial practice, I came to see how algal biofuels projects – as novel areas of investment in both economic and scientific terms –attracted Turkish scientists' interest. To further understand how they embraced algal biotechnologies, I navigated a history of modernization in Turkey. With a background in Turkish modernization process from my MA research and undergraduate training, I was hesitant to follow this line of discussion. I thought that I could not add anything new to the literature. Yet, during fieldwork, I found that my reading of this literature had shifted. I learned to see Turkish modernization as a technoscientific process. This allowed me to think differently about the history of modernization in Turkey and what this dissertation brings to the conversation. That said, my final chapter is not meant as case study of Turkey to add to other studies of bioeconomies. Rather, my goal was to denaturalize the hegemonic model of American bioeconomies, and offer a new perspective on bioeconomies more generally.

I am still in the process of pinpointing what Turkish bioeconomies are becoming. Although this question goes beyond the scope of the dissertation at hand, I see these Turkish bioeconomies as fruitful sites to explore for future research. Notably, my aim is to further unpack the relations between modernity and sustainability. Future research will build on this dissertation's effort to draw non-Western countries into the conversation, so that I can investigate how bioeconomies, more generally, take form.

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