Rethinking the Growth Mantra: An Exploration of the Post-Normal World of Declining Conventional Fossil Energy

by

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Abstract

This dissertation represents a meta-survey of evidence projecting a future of conventional fossil energy decline, and the rapid disappearance of highest quality conventional energy sources. Evidence also suggest that increasing costs of fossil fuel production and declining energetic quality of replacements, point to a growing uneconomic cost of fossil fuel consumption. This indicates the need to challenge the benefits of continued fossil fuel consumption due to the growing devastation on humanity associated with accelerating global climate disruption. Resistance to transitioning away from fossil fuel consumption is documented, with major corporations continuing to promote continued fossil energy consumption using multiple think tanks and political agencies. This dissertation supports the findings of the original 1973 Limits to Growth models projecting an end to the modern "Business as Usual" (BAU) industrial age civilization from two aspects: growing resource depletion, and the expected decline of industrial and services per capita. Evidence indicates that dedicated efforts to continue BAU fossil fuel consumption could end in the collapse of energetic structures essential to industrial civilization, leaving humanity in an energy impoverished position struggling to adapt to increasing global climate disruption. This evidence suggests that the education and knowledge developed in a civilization, where nearly everything created in past generations of increasing fossil fuel consumption risks redundancy in a new ontological world of learning to live with declining per capita energy. This transdisciplinary dissertation surveying these emerging trends in petroleum geology, energy related economics and climate science, collectively dictate that a post-carbon future and the changes that accompany it is one that educators must not ignore.

Preface

This dissertation is the original, unpublished, independent survey of research created by the author Terrance Berg. There are significant numbers of works from other researchers both summarized and presented in this meta-analysis.

Table of Contents

List of Figures

List of Equations

List of Symbols and Abbreviations

1P (proven) reserves

2P (proven + probable) reserves

3P (proven + probable + possible) reserves

AD ... Anno Domini

AGW ... Anthropogenic Global Warming

AMOC ... Atlantic Meridional Overturning Circulation

AOGCMs ... Atmosphere-Ocean General Circulation Models

AOGHS … American Oil & Gas Historical Society

AOSIS ... Alliance of Small Island States

API ... American Petroleum Institute

APPEA ... Australian Petroleum Production and Exploration Association

AR4 ... IPCC Fourth Assessment Report

AR5 ... IPCC Fifth Assessment Report

ARMI … Association of Risk Management and Insurance

ASPO ... Association for the Study of Peak Oil

AVOID … Can we avoid dangerous climate change?

B.P. or bp ... Before Present (re: 1950)

BAU ... Business as Usual

bbl ... barrel

Bbpa ... Billion barrels per year or annum

BCA ... benefit-cost analysis

BP ... British Petroleum

BTU ... British Thermal Unit

CAIT ... Climate Analysis Indicator Tools

CAPEX ... capital expenditure or capital expense

CAR ... Carbon Asset Risk Initiative

CASSE ... Center for the Advancement of the Steady State Economy

Ccf ... Hundred Cubic Feet

CCS ... Carbon Capture Systems

CDIAC ... Carbon Dioxide Information Analysis Center

CICERO ... Center for International Climate and Environmental Research

CMO ... Cubic Mile of Oil

CMOpa ... Cubic Mile of Oil per year or annum

COP ... Conference of the Parties

COP21 ... 21st Conference of the Parties

CoR … Club of Rome

CTI … Carbon Tracker Initiative

CTL ... coal to liquid fuel or Coal to Liquid

DICE ... Dynamic Integrated model of Climate and the Economy

dilbit ... diluted bitumen

DMSP ... Defense Meteorological Satellite Program

EIA ... U.S. Energy Information Administration

ELM ... Export Land Model

EMICs ... Earth System Models of Intermediate Complexity

ENVI … Committee on the Environment, Public Health and Food Safety

EPA ... Environmental Protection Agency

EROI ... Energy Return on Energy Invested

EROIE ... Energy Return on Energy Invested

ESI ... Environmental Sustainability Index

Euracoal ... European Association for Coal and Lignite

EVI ... Environmental Vulnerability Index

FAO ... Food and Agriculture Organization of the United Nations

FAR ... IPCC First Assessment Report

FCCC ... United Nations Framework Convention on Climate Change

FTGTL ... Fischer-Tropsch Gas to Liquid

FUND ... Framework for Uncertainty, Negotiation and Distribution

GCC ... Global Climate Coalition

GDP ... Gross Domestic Product

GEA ... Global Energy Assessment

GFC … Global Financial Crisis

GHG ... Green House Gas

GNP ... Gross National Product

GOO ... Get Oil Out

GOP ... U.S. Republican Party

GPI ... Genuine Progress Indicator

GWP ... Gross World Product

HDI ... Human Development Index

HPI ... Happy Planet Index

HPI ... Human Poverty Index

IAM ... Integrated Assessment Model

IAWG ... Interagency Working Group on Social Cost of Carbon

IEA … International Energy Association

INDCs ... Intended Nationally Determined Contributions

IOC ... International oil company

IPAT ... Impact = Population x Affluence x Technology

IPCC ... UN Intergovernmental Panel on Climate Change

ISEE ... International Society for Ecological Economics

ISEW ... Index of Sustainable Economic Welfare

ITPOES … Industry Taskforce on Peak Oil and Energy Security

lff ... liquid fossil fuel

LPI ... Living Planet Index

LTG ... Limits to Growth

Ma ... Million years

MBI's ... market-based instruments

md ... millidarcies

MDh ... Thousand decatherms

MENA ... Middle East and North Africa

MMbpd … Million barrels per day

MMDth ... million decatherms

MTOE ... Million Tonnes of Oil Equivalent

NGL ... Natural Gas Liquids

NOAA … National Oceanic and Atmospheric Administration

NOC ... Nationalized Oil Company

NRDC … National Resources Defense Council

NSIDC ... National Snow and Ice Data Center

OAPEC ... Organization of Arab Petroleum Exporting Countries

OCI ... Oil Change International

OECD … Organization for Economic Co-operation and Development

OIIP ... Oil Initially in Place

OIP ... Oil in Place

OOIP ... Oil Originally in Place

OPEC ... Organization of Petroleum Exporting Countries

P10 ... 10% chance of recovering more Oil

P50 ... Median estimate of recovering more Oil

P90 ... 90% chance of recovering more Oil

PAGE ... Policy Analysis of the Greenhouse Effect

PIIP ... Petroleum in Place

PIK ... Potsdam Institute of Climate Impact Research

ppm ... Parts per Million

R/P or RPR ... known reserve divided by production

RAR ... Reasonably Assured Resources

RCP ... IPCC Representative Concentration Pathway

RF ... Recovery Factor

ROI … Return on Investment

SAR ... IPCC Second Assessment Report

SCO ... Synthetic Crude Oil

SEDAC ... Socioeconomic Data and Applications Center

SMOC ... Southern Ocean Meridional Overturning Circulation

SOFI ... State of the Future Index

SPE ... Society of Petroleum Engineers

SPM ... IPCC summary reports for policy makers

SPR ... Strategic Petroleum Reserve

SRES ... Special Report on Emissions Scenarios

$SSCO_2$ ... Social Cost of Carbon

STM ... science, technology and medical

TAR ... IPCC Third Assessment Report

Tcf ... Trillion cubic feet

Tcf/a ... Trillion cubic feet per year or annum

th ... therms

U.S. ISAB ... U.S. International Security Advisory Board

UCS ... Union of Concerned Scientists

UKERC ... U.K. Energy Research Centre

UNEP … United Nations Environment Programme

UNFCCC ... United Nations Framework Convention on Climate Change

UNHCR ... United Nations High Commissioner for Refugees

UPR ... Undiscovered Prognosticated Resources

UR ... Undiscovered Resources

URR ... Ultimately Recoverable Reserve

USGS … U.S. Geological Survey

USR ... Undiscovered Speculative Resources

WEC ... World Energy Council

WG1 … IPCC Working Group 1

WI ... Wellbeing Index

WPC ... World Petroleum Council

WSPA ... Western States Petroleum Association

WTI ... West Texas Intermediate

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This dissertation is built on the labours of many scholars, researchers and organizations dedicated to the pursuit of understanding the complexity of the world we inhabit. I express my gratitude to my advisor Samson Nashon and committee members Anthony Clarke and Peter Cole. Their patience, wisdom and advice has been most appreciated and I am fortunate to have had their guidance helping me to work through this. I also want to express my gratitude to a host of scholars and colleagues; Wytze Brouwer, Wayne Ross, Sandra Matheson, Danny Bakan, Ugo Bardi, Paul Richard, Arthur Fallick, Phillip Holden, Richard Khan, Pushkar Sohoni, Richard Kahn, Diane Walsh, Kurt Cobb, Nicole Foss, Robert Rapier, Art Berman, Richard Heinberg, Andy Robinson, Gail Tverberg, James Howard Kunstler to name just a few of the very many who gave me so much inspiration and strength. One of the greatest experiences of my life occurred living at UBC Green College under the guidance of principal Mark Vessey and with its many interdisciplinary residents. They have been a most valued part of this incredible journey. I need to express my gratitude to UBC and KPU for continued support, encouragement and funding to pursue this dissertation as this would not have been possible without them. Finally, my gratitude to my family members Karl, Kyra, Mark, Callista, Caitlyn, Angela, Clark, Felicia, Jasnah and Sally.

Dedication

To my Parents, Children and Grandchildren

Chapter One

Industrial Civilization's Energy Descent Future

> The implication is clear: civilizations are fragile, impermanent things. This fact inevitably captures our attention, and however we might wish otherwise, prompts disturbing questions. Are modern societies similarly vulnerable? (Mazzarino, 1966, pp. 171, cited in Tainter, J., 1990, pp.1).

The fragility and impermanence of industrial civilization stems from its foundation built upon an abundance of cheap but finite amounts of conventional fossil fuel energy. It is in the consumption of this resource that brings an inherent expiry date with it and thereby significant change to all fossil energy consuming and exporting regions (Murphy, 2011; Rubin, 2012). The western world is one such region where this fossil energy consumption defines economy, health and wellness, food, water, travel, work, school, leisure and majority of its products (Conforti & Giampietro, 1997; Rubin, 2009, 2012; Hamilton, 2011). Since conventional fossil energy consumption define the twenty-first century civilization, peak conventional oil[1], fossil net-energy[2] descent, growing climate disruption and economics supporting business as usual (BAU) are significant factors that will leave behind a dramatically altered landscape. Once it is recognized that civilizations need to redefine themselves to live with increasing cost from the

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[1] Peak Oil is defined as the moment when maximum rates of petroleum extraction has been reached after which production falls into a permanent decline. M. King Hubbert in 1956 accurately predicted the peak of U.S. oil production to occur in 1970, using a logistic model which has since been identified as the Hubbert peak theory.

[2] Net Energy Analysis is a technique to evaluate energy systems by comparing the amount of energy available for consumption to the total energy that was used to find, extract, process, deliver, and upgrade the primary source of this energy (Cleveland, 2013).

consumption of remaining fossil fuels[3], it can be expected that the current economic ontological pursuit of growth could face a choice to transition to one of a controlled economic degrowth or outright collapse (Tainter, 1990, 2010; Orlov, 2008; Rubin, 2009, 2012; Martenson, 2010; Murphy, 2011; Kerschner, 2014). In confronting this reality, understanding the factors that underlay a descent of fossil conventional energy should assist in the needed decoupling from unsustainable fossil energy consumption and help guide into a controlled transition towards a low carbon energy future (Krumdieck & Dantas, 2008; Heinberg, 2009b; Robinson, 2009).

Since the 1859 [4, 5] introduction and rapid production of cheap and abundant fossil energy, the industrial age grew at a near exponential rate. Six generations later, evidence supports fossil energy civilizations appearing to have positioned themselves for a likely generation or more of economic turbulence followed by a multigenerational transition of falling net energy fossil production, un-repayable debt[6] and increasing negative externalities[7] that western societies are poorly prepared for (Orlov, 2008; Martenson, 2010; Murphy, 2011; Ehrlich & Ehrlich, 2013).

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[3] Costs of fossil fuel consumption should include negative externalized costs not included in market costs. Externalized costs are described in detail in Chapter Five.
[4] Hubbert (1949) calculated the initial growth rate of petroleum production, a century after the start of the industrial age was a little more than 9% (1860-1929) before slowing (Cleveland, 2008).
[5] 1859 marked the onset of the first oil boom in the United States when Colonel Edwin L. Drake struck rock oil in Titusville, Pennsylvania.
[6] Keen (2015) (Weekly Economics Podcast 2015) predicted the global economic crash of 2008 as inevitable due to the near perfect exponential rise of private debt to GDP, knowing a crisis would arrive when the rate of economic growth slowed. The 2008 economic crash occurred when the rate of GDP growth went negative.
[7] As the cost of these negative externalities increase, the benefit from consuming fossil energy decreases. Calculating the societal costs of fossil fuel consumption is core to estimating what value a carbon tax should be set at (Hope, 2015).

This transition will likely mark the end of present day globalization, perhaps as suggested by Rubin (2009, 2012) due to the disappearance of export trade goods having low value and high transport costs. Industrial civilization is reaching an end to the BAU lifestyle that has ignored limits[8] and must shoulder its responsibility for leaving behind negative externalized costs[9] from its irresponsible behavior to be paid by future descendants (Meadows, Meadows, Randers & Behrens III, 1972; Meadows, Randers & Meadows, 2004; Orr, 2004; Rockström et al., 2009; Kahn, 2010; Ehrlich & Ehrlich, 2013; Barnosky, Ehrlich, & Hadly, 2016). It should become increasingly obvious that the industrial civilization needs to address the question of how it can transition into a future of shared global responsibility, giving the descendants of humanity a future with the chance of hope instead of hopelessness and unsolvable problems (Laszlo, 2003; Jenkins, 2005; Ehrenfeld, 2008a).

For educators to address finite fossil fuel resources in a Limits to Growth (LTG)[10] future, it will be from an ontological reframing arising from the epistemological[11] recognition that humanity, particularly fossil energy consumptive civilizations, must learn to live with restraint and within boundaries (Burbles & Berk, 1999; Clugston & Calder, 1999; Wals & Jickling, 2002; Orr, 2004;

[8] The 1973 Limits to Growth study projected the collapse of civilization unless changes were made to stabilize human consumption and growth. This was aggressively attacked by multiple actors invested in business as usual.
[9] Externalized costs have been a growing part of environmental law for over a half century, arising from the works of Rachel Carson and Ronald Coarse concerning the economic cost of pollution, where individuals, industries, corporations, regions and governments gain an economic benefit from some activity which in turn causes economic harm to others (Plater, 1993).
[10] The Limits to Growth study was a Club of Rome initiative resulting in a two-year MIT study using the computer model World3 to explore the ecosphere's ability to support or sustain increases in human population, pollution, production and continued economic growth (Nørgård, Ragnarsdóttir, & Peet, 2010).
[11] Epistemology in this statement recognizes that knowledge is a mental state and that if an individual does not recognize that limits exist, then they cannot be knowledgeable about them.

Rockström et al., 2009; Sandlin & McLaren, 2010; Kahn, 2010; Bardi, 2011; Barnosky et al., 2016). For fossil energy, the industrial civilization has but a few short decades to replace its least efficient systems with ones using a fraction of previous fossil energy consumption and sourced from carbon neutral sources[12]. No silver bullet or computer application will allow our civilizations to continue as before; rather it will be a transition of reconstructing lifestyles that not only use less energy but can be sustained within the limits of available energy resources. This requires an energy literate civilization divested from a BAU growth mindset and ontologically able to distinguish fact from opinion[13] to create needed changes for our future (Lazlo, 2003, 2011; Orr, 2004; Antunes & Gadotti, 2005; MacKay, 2009; Heinberg, 2009b; Bardi, 2011; Oreskes, 2015; Barnosky, Ehrlich, & Hadly, 2016).

This dissertation summarizes nearly a decade of surveying research to understand the drivers and risks linking peak conventional fossil energy production with the economics of fossil energy consumption and uneconomic externalized costs. Abundant research exists from scientists, engineers, economists, doctors, academics, governmental and non-governmental agencies and industry, where the weight of evidence shows that the industrial civilization must change, yet globally, BAU drivers seem driven to pushing past boundaries that should not be crossed (Rockström et al., 2009; Rockström, Sachs, Öhman, & Schmidt-Traub, 2013).

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[12] Humanity consumes more than 1/3 of all the energy provided by photosynthesis, mostly for foods and biofuels, leaving a shrinking amount for the rest of the ecosystem to share (Barnosky, Erhlich & Hadly, 2016).

[13] Views that characterize fact vs opinion conflicts, where opinion is increasingly "anti-science and anti-intellectual thinking" have been been described by Carl Sagan (1997) as the "celebration of ignorance" and Isaac Asimov (1980) as "my ignorance is just as good as your knowledge.".

Researcher Positionality

I am fortunate to live in a region, rich with resources to explore these risks, able to attend any number of conferences held at UBC, SFU, KPU, VCC and Green College. I have been able to converse with many of the leading intellectuals dedicated to trying to understand the systemic nature of the fossil energy challenges we face.

My background and limitation[14] is that I am a white male, university/college physics instructor who when I became aware of energy/economic/climate risks linked to a BAU ontology, struggled to find ways to answer a personal pedagogical question "What should I reframe in my teaching to prepare students for this emerging world?" I eventually realized that I had ventured into a question of such broad scope that it required a multidisciplinary ontological reframing, the transition away from a BAU mindset[15] and neoliberal university model that currently works to increase funds and resources that encourage unsustainable economic growth targets[16]. To better manage the scope of my work I have restricted my focus to factors influencing the future of

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[14] A limitation of my research is that I fit the standard profile of researchers writing energy papers: male, both working in and affiliated with a North American institution, trained in a field of science, economics or energy studies and where my previous research papers are published within traditional disciplinary boundaries (Sovacool, 2014b).

[15] A teachable metaphorical description of ontological framing comes from the movie, The Matrix (1999) where the character Neo in conversation with Morpheus is offered the choice of a blue pill (allows one to return to a fabricated reality) or a red pill (allows one to escape the Matrix and live in a real world).

> "This is your last chance. After this, there is no turning back. You take the blue pill—the story ends, you wake up in your bed and believe whatever you want to believe. You take the red pill—you stay in Wonderland, and I show you how deep the rabbit hole goes. Remember: all I'm offering is the truth. Nothing more."

[16] One way to understand the need for economic growth is that the growth in GDP should equal population growth to maintain a steady state per capita GDP.

BAU conventional fossil energy consumption. To address my original question of what should I reframe in my teaching, I set to address using the following questions:

1. What is the evidence that the industrial civilization faces a future of conventional fossil energy descent?
2. What is the evidence of the growing uneconomic costs associated with fossil energy consumption?
3. What are the financial benefits/risks and who are the major agencies promoting the consumption of fossil energy?
4. What are options and alternatives to reduce and decouple from fossil energy consumption?

Given that these questions were answered through the analysis of an extensive body of peer-reviewed works with the methodology used being applied throughout this dissertation, no chapter was designated as a methodological chapter. Instead I only outline the methodology used in making sense of the literature to answer the above questions.

Methodology

To investigate these questions, I employed aspects of meta-analysis methodology interwoven with meta-narrative approaches to reviewing, analyzing and synthesizing a body of peer-reviewed research on and related to this topic, focusing on what peak fossil energy means today and tomorrow (Glass, G. V., 1976; Duval, S., & Tweedie, R., 2000; Greenhalgh, T., Robert, G., Macfarlane, F., Bate, P., Kyriakidou, O., & Peacock, R., 2005; Stanley, L., 2008). Further, I drew on notions of mixed methodology in investigating these questions, specifically interpretative studies and document analysis (Walsham, G., 1995; Xu, J., & Croft, W. B., 1996;

Denzin, N. K., & Lincoln, Y. S., 2008; Bowen, G. A., 2009). The interpretative lens focusing this research was not to search for a single theory but a desire to bring to surface the threads connecting disparate literature, to provide a foundation for future research. Document analysis served to engage in detail useful to identifying thematic patterns and links shared among data from multiple disciplines.

The principle grounding this research grew from a desire to synthesize loosely linked bodies of research into a pedagogic document that was credible[17], dependable[18], transferable[19] and confirmable[20]. These principles were core to my analysis and synthesis of data that emerged from peer reviewed studies and while not explicit, interpretations are informed by research.

Important strengths highlighted in adopting this mixed methodology approach are as follows:

- I studied situations as they unfolded which worked to make this research non-manipulative or controlling.
- I remained open to what might emerge when thematically linking this data, meaning there existed no predetermined constraints on the outcomes I arrived at.
- I was able to alter the direction of my inquiry as my understanding increased which allowed me to be unrestrained by a rigid ontology.

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[17] Credibility means that it has internal validity using data that is persistent through a triangulation of multiple sources.
[18] Dependability means that it is reliable by using data that is purposefully global in scope, to ensure a widespread sampling of the body of existing research.
[19] Transferability works to ensure external validity of the synthesized data to accurate describe the shared linkages in data from careful document analysis.
[20] Confirmability works to ensure that there is consistency between the data analyzed and new data that one continues to observe.

• I met with other researchers to get firsthand their personal insights, thoughts and experience allowing for greater depth beyond published research.

In summary, this research format allowed me to understand the dynamics linking multiple disparate works and works to better understand it's overall contextual complexity of interdependencies. This research framework allowed me to immerse myself in the details and specifics of the data, to then work in identifying important categories, themes, dimensions and/or interrelationships that emerged.

In adhering to this investigative framework, in excess of 11,500 papers, reports and conference proceedings were searched, taking over 8 years. This research approach confirmed some weaknesses outlined in using a framework of interpretative studies and document analysis in its warning that it can be time consuming and that one often runs into issues concerning how much data is enough for the study (Walsham, G., 1995; Denzin, N. K., & Lincoln, Y. S., 2008).

My objective in doing this research is to encourage teachers and others to join in this conversation, making use of abundant resources that help one to understand this complex, confusing and contested world of BAU fossil energy consumption[21]. The problem as I eventually came to understand from my research is that:

[21] The use of "contested" to me is an understatement in a war of propaganda being raged in trying to keep the BAU economic system going even though profits gained are in some areas dwarfed by negative externalized costs.

> **"Humanity needs to understand fossil energy consumption from a different ontological framing than one of continued support and/or acceptance of BAU growth and consumption."**

This reframing away from a BAU ontology is needed by educators to enable them to redesign epistemological approaches and to help find needed alternatives, be they personal, regional or global[22]. May we all be granted the moral courage needed to go forth and help write a future, one that I hope to become a post carbon renaissance celebrating living healthily and happy within a world of limits.

Dissertation Overview

This dissertation is constructed in a meta-narrative form, with chapters 2-6 focusing on various conventional fossil energy questions to construct a conventional fossil energy ontological framework[25] linking fossil energy economics, externalized costs and petroleum geology. This design is purposeful as it has theoretical, curricular and pedagogical implications.

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[22] Symington, Cripps, Clark & Tytler (2013) Identify the need for academic educators and researchers to step outside the career building demands to publish in peer reviewed journals and to work towards identifying "more diverse and well planned communication approaches" (pp.8) which should become central to planning their research.

[25] Sovacool (2014b) reports a call from Paul Stern (1986) to broaden energy research to include insights and tools as a method to explain more fully energy phenomena. Sovacool's critique of energy research goes on to state

> that existing forms of energy research have discouraged interdisciplinary interaction and breadth. And they have argued that much of what energy researchers produce is irrelevant to what actual energy policymakers and businesspersons consider important (pp. 1).

Chapter two, **Fossil Energy Production: Models and Risks** surveys theories of resource depletion and models of limits, from Thomas Malthus on population overshoot, to the more recent systemic Limits to Growth (LTG) study. The LTG study is further supported by Tom Murphy on the physical limits to energetic growth, Hubbert Peak Theory on conventional resource production and the Capital-Resource, Predator-Prey Model. While these theories and models are not exhaustive, research is showing that the industrial civilization is closely tracking the LTG BAU scenario and heading into a depleted conventional energy future facing wicked problems where solutions to some problems create other problems and sometimes multiples (D'Alisa & Kallis, 2015). As civilization becomes increasing rigid and complex from specialization and globalization, it becomes increasingly fragile facing an increased possibility of black swan events[26] that could cause multiple systems to collapse (Tainter, 2010; Taleb, 2010, 2012). The industrial civilization is heading into a future that can be defined as post-normal (compared to the current normalized fossil fueled industrial age) using the Kuhnian understanding that collectively humanity has stepped outside the paradigm of BAU growth[27] (Kuhn, 1962, 1970; Tainter, 2010).

[26] Nicholas Taleb in his work *The Black Swan-The impact of the Highly Improbable* (2007, revised 2010), popularized black swan events as ones that are rare and improbable having high impact.

[27] Hubbert back in 1949 argued that the petroleum fueled industrial age is not normal, something that is easily "seen by backward extrapolation" Cleveland (2008).

The third chapter: **Fossil Energy Metrics: Understanding the Conversation** is needed to understand fossil energy conversations[28] using emerging terms and definitions such as EROI[29], Net Energy, various classifications of fossil reserves and resources, energy densities and qualities. Using these terms and definitions, this chapter then addresses the first question: "What is the evidence that the industrial civilization faces a future of conventional fossil energy descent?" Evidence is gathered to illustrate the decline in availability and decreasing quality of the conventional fossil energy resources of oil, gas, coal and uranium, increased growth of unconventional liquid fossil fuels and of other lower quality fossil energy resources.

The fourth chapter: **Fossil Energy Consumption: The Cost of Externalities** addresses the second question: "What is the evidence of the growing uneconomic costs associated with fossil energy consumption?" In exploring this, I look at the impact of fossil fuel consumption and how negative externalities arising from its consumption and other human activity has led to describing the current geologic epoch as the Anthropocene[30] transitioning from the Holocene. Central to quantifying Anthropocentric social costs is carbon dioxide released from burning carbon based fuels[31], forcing all of humanity to adapt to increasingly unpredictable and

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[28] Fossil energy is stuck in a pre-metric age, where it can be measured differently within the same country.

[29] EROI is a measure of the Energy Return on the Energy Invested to get the energy source. It is a term adapted from Economics, the "Return on Investment" (ROI). EROI is covered in more detail in "EROI and the Net Energy Metrics" in Chapter Two.

[30] The Anthropocene proposed by Crutzen and Stoermer (2000) describes the time interval from the later part of the 18th century as one that human activities had moved the earth into a new geological epoch from the Holocene ("Recent Whole"). While not formalized the Subcommission on Quaternary Stratigraphy (2016) has proposed that the date of 1950 marks a new epoch where a "great acceleration" from fossil energy consumption, plastic pollution and radioactive fallout from nuclear testing will alter all future geologic sediment records (Voosen, 2016).

[31] EPA (2015) "Social Cost of Carbon" chart that gives the economic cost of adding 1 metric ton of CO_2 in a given year. Link: https://www.epa.gov/climatechange/social-cost-carbon

disruptive weather patterns, uncertain food and energy production, and prepare for numbers of migrating refugees from climate disrupted regions (Dyer, 2009; Hsiang, Burke & Miguel, 2013; Hsiang & Sobel, 2016). Three major agencies are discussed in this chapter: The Intergovernmental Panel on Climate Change (IPCC) in their synthesis of expected climate impacts, United Nations Conference of Parties (COP) in their efforts to bring political action to the reduction of carbon fuel consumption and Carbon Tracker Initiative (CTI), an independent financial think tank that explores financial risks in investment in carbon fuel source development.

The fifth chapter: **Fossil Energy: Economic Factors** focuses on answering the third question: What are the economic benefits and who are the major agencies promoting the consumption of fossil energy? This chapter focus on human created systems; civilizations, geopolitics and economics starting with fossil energy joining the industrial age labor force[32, 33]. The link between energy consumption and Gross Domestic Product (GDP) is statistically significant, and economic growth and decline have been found to correlate the rise and fall of fossil fuel usage. Economic linkage demands one address what is the Energy Return on Energy Invested (EROI or EROIE) level needed to maintain industrial civilization and what this metric tells us about the

[32] Andrew Nikiforuk (2012) has recently worked to popularize the concept of fossil energy usage as one similar to slavery usage in the past. A CBC interview from October 22, 2012, describes his "Energy of Slaves". Link: http://www.cbc.ca/books/2012/10/andrew-nikiforuk-explains-why-oil-dependency-is-a-lot-like-slavery.html

[33] In 2011, global daily consumption of a little over 85 million barrels of liquid fossil fuel (conventional) represents the energy equivalent around 21,000 hours of human labor for each barrel. When standardized to represent all fossil fuel consumed (coal, gas, nuclear), this equals a global total of 1.8 trillion hours of human labor. North America uses about 20% of this amount, which means that each American receives the rough equivalent of 5100 hours of fossil fuel labor, or the equivalent of 640 human servants, which increases to 1900 when one includes all forms of energy that is consumed.

economic differences between pre-peak, plateauing and declining conventional fossil energy economies.

Oil equals wealth and power and the control of this power displayed itself through the tensions emerging from the 1973 OPEC oil embargo creating the first OECD oil shock[34] and the economic[35] and societal chaos created from the loss of just a few percent of oil imports into the U.S.A. More recently, the continuance of resource wars is linked to oil in the controversial invasions of Iraq[36], NATO bombing of Libya, and support of Syrian rebels in their efforts to overthrow the government of Syria. These military interventions have worked to cripple fossil energy exports from these regions, which when combined with regional growing internal consumption, mismanagement of resource extraction and the growing capital exploration costs (CAPEX) in companies working to maintain a supply of fossil energy reserves, all point to an impending crisis of increasing turbulence of fossil energy supplies.

Chapters two to five outline the factors leading to the sixth chapter: **Options & Obstacles to Altering Fossil Energy Consumption**. In this chapter I explore my fourth question: What are options and alternatives to reduce and decouple from fossil energy consumption? While I do not outline what pathway must be taken, I survey research that governmental and Non-Governmental

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[34] The OPEC oil embargo resulted in increased interest in research over the link between energy and economy (Murphy, D. 2014).
[35] Economists use two models (productive economy is reduced and inappropriate macroeconomic policies) to explain the stagflation resulting in seven OECD nations from 1973-1982 with both crediting the huge rise in oil prices as its origin. The term stagflation was first used in 1965 UK to represent the merging of inflation and stagnation of the economy (Blanchard & Gali, 2007).
[36] Greg Muttit (2011) "Fuel on the Fire-Oil and Politics in Occupied Iraq" list several memos showing oil company Iraqi oil field interest prior to invasion. Further detail can be found at: http://www.fuelonthefire.org/?page=documents#1597.

Organizations have been working on to transition away from the BAU mindset. This chapter outlines alternatives to policies built upon GDP and highlights emerging degrowth movements and other effective ways and means to decouple away from fossil energy intensive lifestyles. These are all active steps toward challenging hopelessness in the face of dystopian or apocalyptic visions of the future. This chapter concludes with some of the challenges including repaying of debt due to the limits of growth, and addresses the malfeasant behaviour coming from fossil energy funded climate obstructionist organizations[37] who along with the collaboration of governments work to delay political and public response in curbing fossil consumption.

The seventh and concluding chapter: **Conclusions and Implications** addresses concluding thoughts on my founding question, "What do I teach?" While not prescriptive, I seek to summarize the evidence presented in this dissertation and overlay this with my personal thoughts, observations and points of interest that I see as needing further investigation.

The driving factors supporting the creation of this dissertation rises from my personal awareness in the evidence that the industrial civilization is facing numbers of challenges rising from the production and consumption of lower quality fossil energy sources resulting in increasing production and externalized costs. These costs cannot be ignored since they manifest themselves in all aspects of civilization engaged in any enterprise of production and consumption of fossil fuel. These costs must distinguish who benefits and who is paying from the consumption of fossil fuels, from the first peoples of the Americas who are most recently fighting to protect the

[37] The Union of Concerned Scientists (UCS) (n.d.) provides a list of fossil fuel funded organizations. Further detail can be found at: http://www.ucsusa.org/global_warming/solutions/fight-misinformation/global-warming-skeptic.html#

right to clean water in North Dakota to the many civilizations living on low lying islands or lands that are about to vanish due to rising sea levels and will be forced to move.

Energy literacy must grow to account for the rising costs to all of humanity and of diminishing benefits to the few to argue that the industrial civilization must rethink BAU drivers touching all parts of the world. The evidence is clear that many alternatives to its previous ways of the industrial civilization must be found. May we all be graced with the intelligence and wisdom needed to make the needed rapid transition to embrace a post carbon future.

Chapter Two

Fossil Energy Production: Models and Risks

Do not confine your children to your own learning for they were born in another time (Hebrew Proverb).

Globally, the production of all conventional fossil sources of energy[38] will have peaked or be near-peaking by 2025 (Ingles & Denniss, 2010; Owen, Inderwildi, & King, 2010; Maggio & Cacciola, 2012; Sorrell, Speirs, Bentley, Miller & Thompson, 2012; Chapman, 2014; Bentley & Bentley, 2015; Warrilow, 2015). When this occurs, this lifeblood of the modern, complex, global civilizations will ensure that the lives of all humans begin an energy transformation characterized by growing climate disruption, increasing fossil energy production costs and corresponding economic impacts. Those who will experience the greatest transition (or shock) will be ones who currently have the greatest invested dependency in fossil energy. Since the western industrial world is the greatest per capita user of fossil energy, it shall be those sharing this high energy consumptive lifestyle who will experience the most severe of expected corrections. Humanity, especially those living the western lifestyle, have reaped tremendous benefit from the cheap

[38] The creation of fossil fuels range from millions to billions of year ago. Uranium, the most ancient of these fuels, finds its birth from highly energetic explosions of supernovas, and as such predate the creation of the earth. Coal originates from the plant remains from swamp and peat bogs from three geologic ages: Carboniferous (360-290 Ma, million years before present or mega-annum), Jurassic-Cretaceous (200-60 Ma) and the Tertiary (65-2 Ma) (Heinberg, 2009a; Höök, 2010). Oil and gas originates from algae that settled on the prehistoric sea beds from the Cretaceous (145-65 Ma) and the Cenozoic (65 Ma to present) of which 70% of all reserves were formed in the past 100 Ma and 40% in the last 30 Ma (Heinberg, 2009a; Höök, 2010). With oil, gas and coal deriving from organic matter that grew from sunlight, and uranium derived from supernovae, all fuels can be considered as stored energy from the sun. These energy stores are clumped in areas throughout the earth and only small amounts have collected in large enough deposits to be worth the effort of extraction.

fossil energy sources over the past one hundred fifty years. While net-energy growth from conventional oil has plateaued[39], with uranium, coal and gas set to plateau within a little over a decade, the structure of energy descent is still uncertain (Heinberg, 2007; Matutinovic, 2011; Garcia, 2012). What one can be relatively assured of however, is that the industrial civilization will face a future of increasing energy costs, uncertain growth in non-conventional fossil energy, increased pollution and accelerating ecosystem destruction, in part resulting from continued consumption of conventional and unconventional fossil energy (IEA, 2016). There are economic, social and environmental reasons why poorer grade energy sources had been left untouched for decades, and the industrial civilization must soon understand the externalized cost humanity will pay to extract and use these remaining fossil energy sources, since it is a price already manifesting itself in a complex multiplicity of Faustian forms (Lazlo, 2003; Rockström et al., 2009; Hansen et al., 2013; Rockström et al., 2013; Capellán-Pérez, Mediavilla, de Castro, Carpintero & Miguel, 2014, 2015; IPCC, 2014; Jarvis & Hewitt, 2014; Hope 2015; Barnosky et al., 2016; Hansen et al., 2016).

Elahi (2011) enlists the metaphor of HIC SVNT DRACONES[40], a phrase that brings a warning of "Here be Dragons," in his description of a future that treads into unknown territories. He uses

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[39] Conventional oil refers to sources of free-flowing liquid oil whereas non-conventional or synthetic oils refer to bitumen (tar sands) and kerogen (shale oil) sourced oils along with natural gas liquids such as propane, butane and ethane. The production from all conventional sources has plateaued within a 5% range since 2004 (Hirsch, Bedzek & Wendling, 2010).

[40] "HIC SVNT DRACONES" in its Latin form has only been found on the Hunt-Lenox Globe (ca. 1503-1507). This is speculated to refer the mythical creatures of the unknown, shown on early maps which contain numerous references and images of such creatures, both real and fictional, perhaps in direct reference to Komodo dragons in Indonesia. Romans used a similar phrase "HIC SVNT LEONES" or "Here are Lions" for denoting unknown territories. Further detail can be found at MapHist: http://www.maphist.nl/extra/herebedragons.html

this to detail the risk management and uncertainty of decision making in a world beset by realities unexplored through current disciplinary focus, where there is reluctance to navigate the tensions of disciplinary boundaries and surrounding unexplored avenues of inquiry (Butler, 2009; Evans, 2009). The metaphor “Here be Dragons” aptly frames the ontological blindness of the coming post-normal energy world, since it is a world that has yet to be experienced by humanity. This post-normal world is characterized by both uncertainties over the nature of the coming energy descent, and the certainty of entering a future dictated by diminishing conventional fossil fuel energy (D’Alisa & Kallis, 2015).

In 2010, the Post Carbon Institute research fellows summarized five key assumptions depicting the industrial civilization’s future below:

1. The industrial civilization has hit a limit to growth and must learn to adapt to resource constraints.
2. The challenges facing the industrial civilization are interlinked, which require a systemic, holistic approach to dealing with them.
3. These challenges cannot be solved as isolated problems, rather they are predicaments, without solutions and require systemic responses.
4. The future is uncertain and the best response to uncertainty is one of resiliency that allows one to “manage unforeseen shocks” and maintain one’s identity.
5. Humanity is not powerless in the face of these challenges; it can act and must be empowered to act and meet the fore-coming transitions that the industrial civilization will face.

(Adapted from the Post Carbon Reader, Heinberg and Lerch, 2010)

The challenge for educators is not only to explore critical questions of how the industrial civilization will transition into this post fossil fuel era, but how curricula and pedagogical approaches should be reframed to assist this transition. This is increasingly exacerbated by BAU interests in expanding the consumptive world, where convenience and consumer items such as iPads, cell phones and designer clothes are being framed as essential needs for civilization (NRDC, 2015). With the coming post-normal energy descent potentially ensuring near disappearance of this consumptive lifestyle, educators must allay societal fears over the loss of excessive consumption and learn to embrace sufficiency and curiosity in working to explore and create a future of hope and promise. The challenge however is to reframe curricula and pedagogical approaches to best navigate a forthcoming post-normal future beset with dragons (Heinberg, 2009b, 2012b; Turnpenny, Jones & Lorenzoni, 2010; Castro e Silva & Teixeira, 2011; Gary, 2011; Kapoor, 2011; Lüthje, Scheffran & Schäfer, 2011; Gasper, 2013; D'Alisa & Kallis, 2015; Alexander, 2016).

The End of Growth and Emerging Post-Normal Future

What does the future entail? This is not a trivial question for educators as they are charged with the task and responsibility of preparing the next generation with needed skills for the future. This future, as inferred from our knowledge of the past, results from over one hundred fifty years of industrial civilization growth using cheap fossil fuels (Hallock, Wu, Hall & Jefferson, 2014). The ontological framing of the developed BAU world is one of continuous near exponential growth, where wealth, consumption, and population have continued to grow beyond all previous human history. However, if one scratches beneath this shiny veneer of growth, one quickly can find limits and restraints that could be devastating to humanity and as such, it becomes prudent to repeat the poignant warning of HIC SVNT DRACONES.

Thomas Malthus

Current economic models governing nearly every corporate, economic and government BAU policy and agenda committed in plans for continued or infinite growth beg the question: How realistic is growth? One of the earliest to question growth was Thomas Malthus (1798) who penned "An Essay on the Principle of Population," broaching the need for humanity to rein in population growth, fearing growth beyond regional carrying capacity[41, 42] (Young, 1969; Hardin, 1998; Smail, 2002, 2003a, 2003b; Nekola et al., 2013). Malthus questions grew from his concerns of arithmetic[43] and exponential[44] growth in that human population can grow exponentially, whereas historically food production grew arithmetically (Young, 1969; Nekola et al., 2013). Malthus believed that the rise of large families went hand in hand with poverty, which in turn ensured a world of increasing poverty, misery and even greater loss of life than that observed during famine[45] and pestilence (Smail, 2002, 2003a, 2003b). His linkage of population growth to poverty, however, quickly generated critical reaction to his essay (Bellany, 1994; Hardin, 1998; Nekola et al., 2013).

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[41] Man is confined in room. When acre has been added to acre until all the fertile land is occupied, the yearly increase in food must depend upon the melioration of the land already in possession. This is a fund which, from the nature of all soils, instead of increasing must be gradually diminishing (Malthus, 1798, Chapter II).
[42] Carrying capacity is a nautical term originating in the amount of freight a ship could safely carry (Sayre, 2008).
[43] Arithmetic growth is growth by the addition of a certain amount in a uniform time frame, such as adding two fruit trees to an orchard each year: 1st year = 2 trees, 2nd year = 4 trees, then 6, 8, 10, 12, 14, 16, 18, until the 10th year = 20 trees.
[44] Exponential growth is a doubling phenomenon of a certain amount in a uniform time frame, such as doubling the number of cats in a farmyard each year: 1st year = 2 cats, 2nd year = 4 cats, then 8, 16, 32, 64, 128, 256, 512, until the 10th year = 1024 cats.
[45] Chalisa Famine in India, 11 million perished (1783-84), Bengal Famine in India, 10 million perished (1770) and after his essay was published, four other famines in China, 45 million perished (1810-49). Further detail can be found at: http://en.wikipedia.org/wiki/List_of_famines.

Debate soon moved beyond controversial reactions to Malthus and his earlier recommendation of abstinence and celibacy into a rebirth of a neo-malthusian movement promoting birth control through contraception (Martinez-Alier and Masjuan, 2008). Pellegrini (2012) documents two neo-malthusian movements emerging. The first was a lifeboat ethic, promoting a policy of anti-immigration, akin to keeping those in the water from climbing in the lifeboat, where they might capsize it and drown all. The second championed the right of humans to control their population growth through contraception. The second movement required stronger freedom for women for this to occur and soon found strong support from wide regions, feminist movements, socialists, intellectuals and anarchists, and is a struggle that continues to this day (Martinez-Alier and Masjuan, 2008).

Resistance to neo-malthusian movements[46] came from the Catholic Church, from French, English, German and United States and other governments perceiving this as a hindrance to their formation of large militaries, promotion of immorality and later from corporations and business that saw population growth as the way to increase profits (Pellegrini, 2012). This resulted in numerous individuals jailed, confined to psychiatric asylums and banished from different countries coinciding with introduced legislation that banned outright contraception and organizations based on neo-malthusian assumptions (Martinez-Alier and Masjuan, 2008).

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[46] This resistance has carried on in various cornucopian movements, in particular Julian Simon's 0pposition to the Limits to Growth (Aligica, 2009).

Limits to Growth

In 1972, the Limits to Growth (LTG) study emerged from MIT using the World3 computer model projecting various scenarios of the future, that accounted for population, natural resources, food production, industrial output and pollution[47]. This Club of Rome (CoR)[48] commissioned two-year study generated results that pointed to increasing pollution, depleted natural resources, failing industrial output, services, and population decline by 2030 (Christakis, 2006; Meadows, 2007; Turner, 2008; Nørgård, Peet and Ragnarsdóttir, 2010). The prognosis of collapse, despite numerous computer scenarios run with this model, ended in collapse for any scenario that allowed continued population and industrial growth (Turner, 2008, 2014, 2015). Graham Turner (2014) in analyzing the standard run of the World3 modeling BAU, projects symptoms of systemic global crash as early as 2015[49].

Published a few years after humans landed on the moon in an age of optimism and rapid growth of wealth, reaction to the LTG study moved quickly into one of personal criticism, attacks and insults from many fronts, specifically business and industries (threat to growth in business), professional economists (academic threat on their dominance of economic affairs), the Catholic Church (population growth), the political left (seen as an attack on the poor) and politicians and others who believed in the promise of infinite growth as the solution to all problems (Nørgård et al., 2010; Bardi, 2011; Turner 2015). Eventually, these assaults reduced the public perception of

[47] The original Limits to Growth study did not include the pollution concerns arising from CO_2 fossil fuel emissions or the depletion of fossil fuels, but overall trends of these two correlate to projected LTG pollution and resource depletion (Nørgård, et al., 2010).
[48] A short history of the Club of Rome can be read in the "Problematique and the Club of Rome" by Ken Bausch and is retrievable at http://quergeist.net/Problematique_Club-of-Rome.htm.
[49] Turner (2014) found evidence that systemic crashes under the BAU scenario will be visible in 2015 starting with per capita industrial output beginning a sharp decline.

the LTG study to "Chicken Little with a Computer" and that the present two-century run of growth in Western economics would never run into any limits (Nørgård et al., 2010; Bardi, 2011). These attacks even included the editor of a prominent academic journal by his surprising refusal to allow a rebuttal from the Limit to Growth authors, imposing a self-styled censorship (Bardi, 2011).

In 2004, "The 30-Year Update" showed civilization's route to collapse was trending close to the BAU World3 model prediction as can be seen in Figure 2.1 (Meadows et al., 2004). At this point

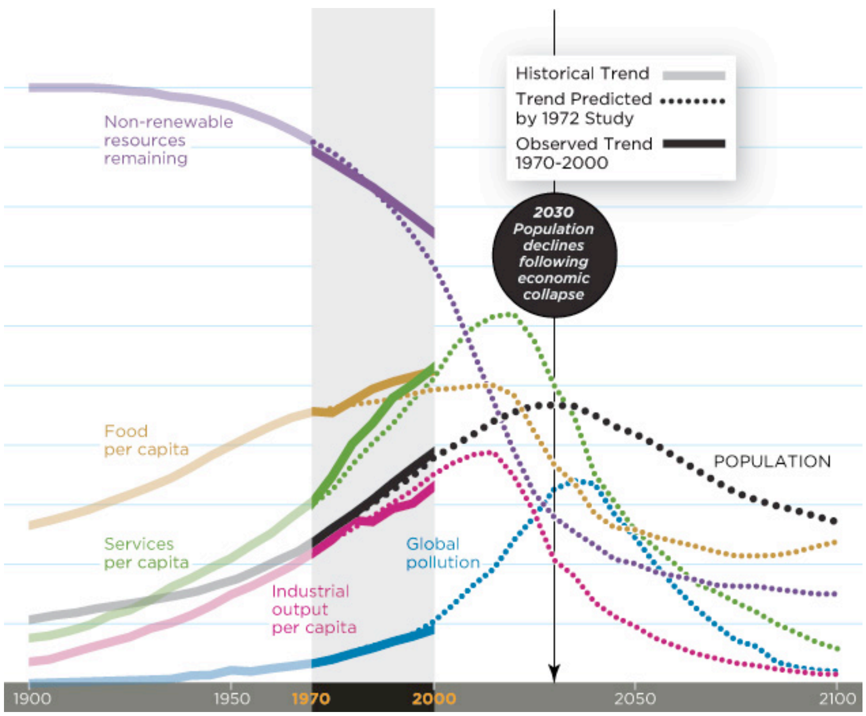

Figure 2.1 The projected trend of the BAU LTG model compared to 28 years of measured data (Source: Hall and Day, 2009)

the original authors decided not to write any updated editions of the Limits to Growth as "they would only be documenting the collapse, rather than acting to try to prevent it" (Heinberg, 2012a). Turner's LTG Studies (2008, 2014, 2015) at the University of Melbourne have generated the most current results supporting that the industrial civilization is currently tracking the BAU scenario outlined in the original Meadows et al., (1972) study. "In particular, contemporary peak oil issues and analysis of net energy, or energy return on (energy) invested, support the Limits to Growth modeling of resource constraints underlying the collapse" (Turner, 2014, pp. 3).

One of the findings that surprised Turner (2015) was that technological discoveries[50] will not save civilization from projected collapse. What he discovered was that technological innovation had to be scaled to five-fold of what the best of present innovation achieves and that this new technology had to be utilized immediately and not in the typical ten to twenty-year timeframe of technological adaptation. Compounding this was the projected social unrest stemming from mass unemployment expected as outcome of technological gains. Jevon's paradox[51] was also expected from increased economic growth, leading to greater buying, consumption and resulting in even greater pollution (Hopkins, 2012; Motesharrei, Rivas & Kalnay, 2014). Following this path, population would grow until 2030 before food and health problems began to reduce human population by a half billion per decade defining itself as a classic wicked problem in using technology to maintain a BAU trajectory. Turner (2014, 2015) remains unsettled by these model projections as he believes that governments are not ready for a LTG future due to many vested interests in maintaining BAU. Impacting growing numbers of humanity, the risk of global

[50] Meadows, Rander and Meadows in their original studies were also quite surprised that technology would not prevent collapse, the opposite of what they had expected (Turner, 2015).
[51] William Stanley Jevons in his work *The Coal Question* (1865) concluded that there could be a rebound effect in technological efficiency gains, in that the more efficient use of coal in mechanical engines would lead to increased usage of coal. This dictates that efficiency gains might backfire in reducing consumption and instead would be increasing consumption (Alcott, 2005; Motesharrei et al., 2014).

collapse if not imminent, is in the near future and entails a fairly rapid drop in population, standard of living and an unraveling of civilized behavior (Orlov, 2008; Martenson, 2010; Nørgård et al., 2010; Tainter, 2010; Bardi, 2011; Hirsch, 2012; Hopkins, 2012; Randers, 2012; Motesharrei, et al., 2014; Turner, 2014, 2015).

Physical Energetic Limits to Growth

Tom Murphy (2011)[52] in analyzing the energy growth rate for the U.S. from the year 1650 through to 2010 (see Figure 2.2) shows a near constant growth rate of 2.9%[53]. In taking these results and extrapolating them into the future, to see how long the U.S. could continue its exponential growth in energy consumption, Murphy reduced and assumed a growth rate of 2.3%.

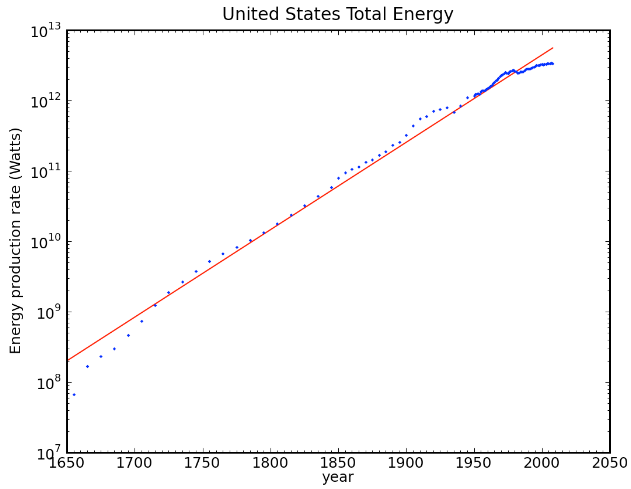

Figure 2.2 U.S. energy growth from 1650 to 2010
compared to an exponential trend of 2.3% growth

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[52] Tom Murphy writes a blog called "Do the Math" where he explores numerous topics using physics. It should be recommended for any curriculum on fossil energy literacy. Further detail can be found at: http://physics.ucsd.edu/do-the-math/

[53] Plotting a logarithmic graph of energy consumed in the United States, a growth rate of 2.9% can be found by calculating the average slope of the line.

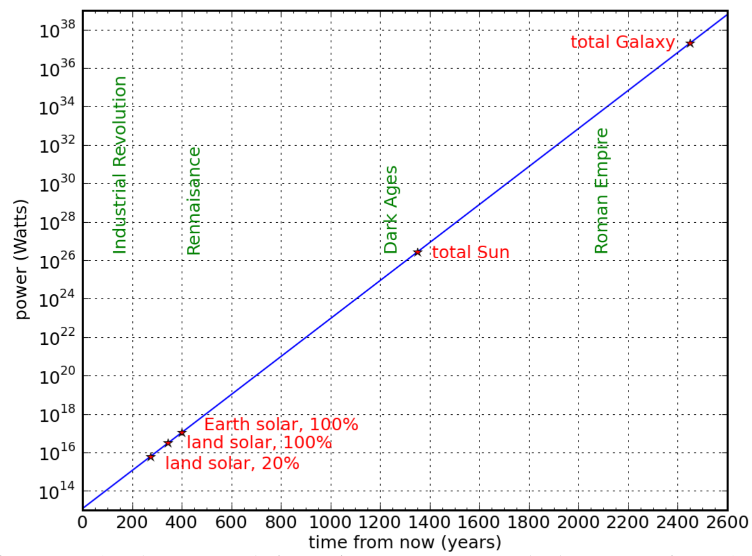


Figure 2.3 The growth in solar energy needed to sustain 2.3% US energy consumption (Source: Murphy, T., 2011)

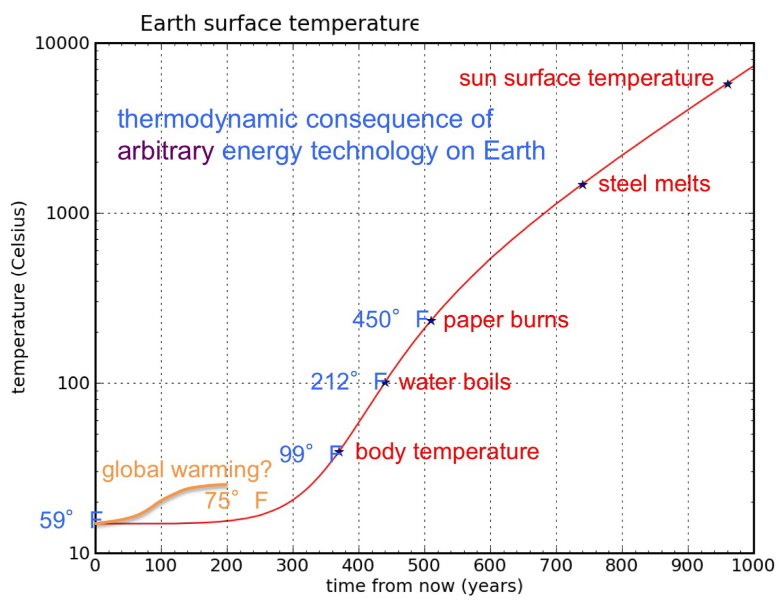


Figure 2.4 The associated heat waste with a growth in US energy consumption at 2.3% (Source: Murphy, T., 2011)

If one assumes the future of industrial civilization's energy production is solar energy, within three hundred years, 20% of all light landing on the surface of the earth would be used, four hundred years 100% of all light from the sun landing on the earth, one thousand three hundred and fifty years to using all the light emitted from the sun and less than twenty-five hundred years to capture and use all the light emitted from our galaxy (see Figure 2.3). If one were to develop fusion to power industrial civilization's needs, the problem then arises in trying to emit the waste heat energy that is produced. In this scenario, the earth's oceans boil in about four hundred fifty years and reach the surface temperature of the sun in a little over nine hundred fifty years as shown in Figure 2.4. Physics therefore dictates that there is a finite limit to the growth of the energy based industrial civilization (Murphy, T., 2011).

Murphy's analysis illuminates that an ontological framework of BAU infinite energetic growth on the planet earth is impossible. Peak conventional fossil energy, however, dictates a much earlier end to growth from the earth's finite fossil fuels (Tomabechi, 2010; Heinberg, 2012a; Chapman, 2014). This evidence when combined with evidence linking economic growth with conventional fossil fuel consumption points to a future of stalling and collapsing economic growth, and a retrenchment back to an economic level that sustainable energy resources can maintain (Martenson, 2010; Murphy & Hall, 2011b; Tverberg, 2011a; Hamilton, 2011, 2012; Hall and Klitgaard, 2012; Menegaki, 2014; Rees, 2015).

Hubbert Peak Theory

Oil shortages have been predicted for several decades, through the 1920s to 1940s (Friedrichs, 2010) but it was Marion King Hubbert who in 1956, through analyzing logistic curves of conventional oil well production, predicted that a peak of production in the United States would occur around 1970 (Hubbert, 1956; Wirth, 2008). U.S. conventional oil production did peak in 1970 (see Figure 2.5), and since then oil fields scattered around the world have been both producing and depleting as projected from Hubbert's peak conventional oil theory (Gallagher, 2010).

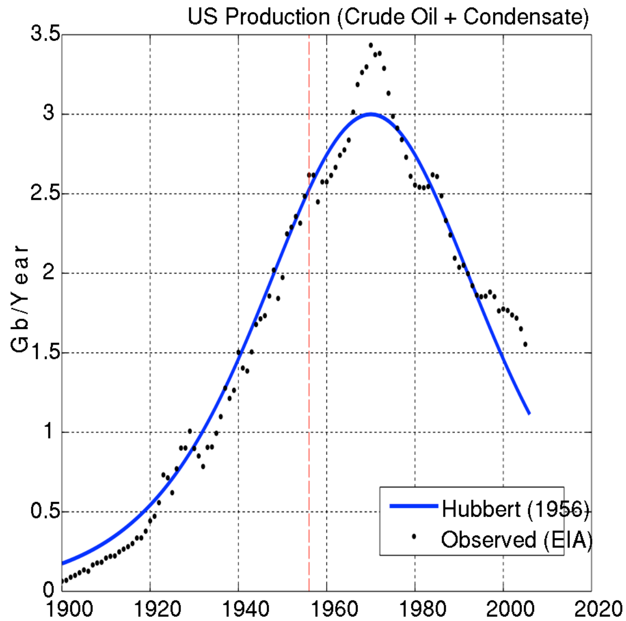
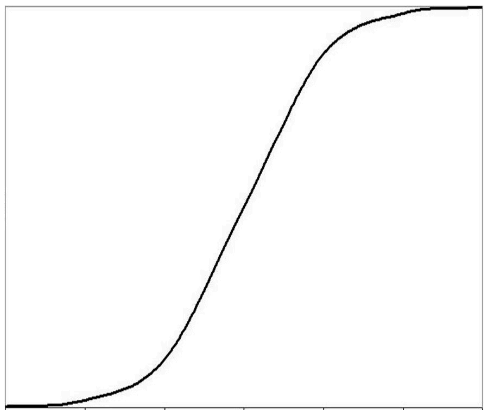


Figure 2.5 The expected trend of conventional oil production (crude + condensate) compared to actual. The bump up around 1984,5 represents Alaska oil coming into production (Source: Hall and Day, 2009)

Logistic curves originated in 1845, where Verhulst discovered and used it in work with population studies. The shape traced by this curve starts out from zero, curves up exponentially, reverses the curve at an inflection point to reach a plateau. This curve, called the S curve is shown in Figure 2.6, allows one to measure and visualize the rate of growth.

Hubbert in taking the derivative of the logistic S curve (see Figure 2.7) arrived at the Hubbert curve, similar in shape to the bell curve. Since the derivative measures how much the original resource curve is changing, it gives a measure of the rate at which the resource is created, extracted or produced. For conventional oil, gas and coal production, the curve starts out showing minimal production from the field, accelerates, then slows to a stop at peak production before beginning a descent back to zero.



Figures 2.6 Shape of a S-curve (Source: Unknown, n.d.)

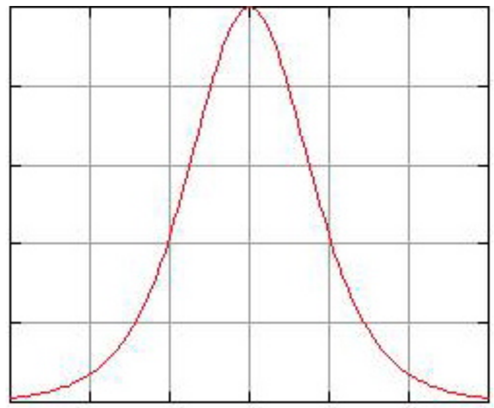


Figure 2.7 Shape of the Logistic Regression curve from its derivative (Source: Unknown, n.d.)

Hubbert's predictions rose from the study of the cumulative production over an entire region of wells, which when combined formed a curve like the classic bell curve which is shown in Figure 2.8. Individual wells carry a different shape and typically show a plateau of a maximum sustained production before they head into permanent descent. Hubbert's curve not only models the production of oil for a region, but also matches production curves from other nonrenewable and renewable resources (Höök, 2010). Illustrating this are two different resource extraction curves (Figures 2.9 and 2.10), that show anthracite mining, and eighteenth century whale oil and bone production.

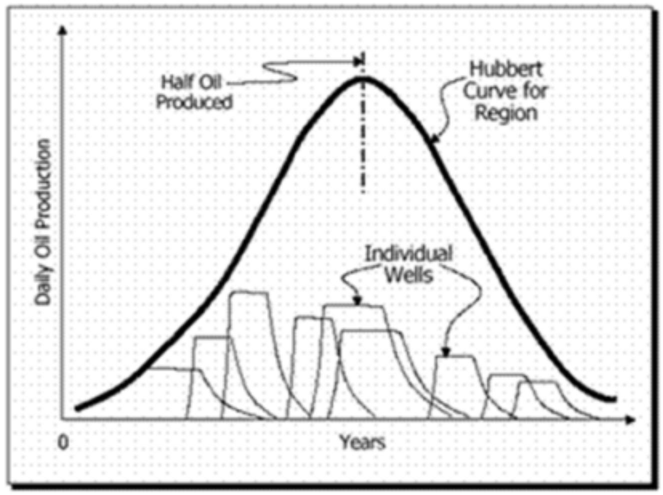


Figure 2.8 The Hubbert Curve as a result from combining production of multiple wells in a given region (Source: Energy Bulletin, 2011)

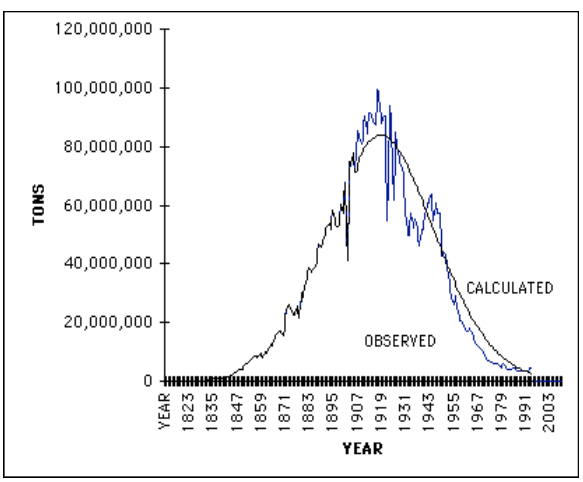


Figure 2.9 Anthracite Coal (Pennsylvania) showing the observed and calculated curves of production for the years 1834 to 1994, where perturbations from the calculated reflect the impact of the depression and World War II (Source: USGS, 1997)

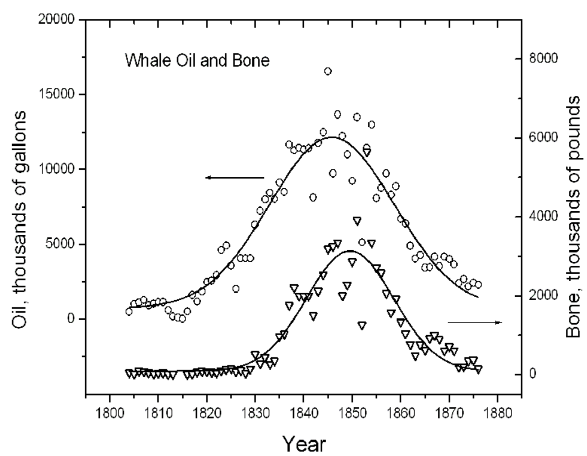


Figure 2.10 Whale Oil production shown as the upper curve and Bone Harvest shown as the lower curve for the years 1790 to 1890 (Source: Höök, Bardi, Feng & Pang, 2010)

Hubbert Peak theory is best applicable to conditions unencumbered by political, environmental or economic manipulations[54], where a large population of fields are available to exploit, and where fields share common geological properties (Kerschner, 2014; Okullo, Reynès & Hofkes, 2015; Reynes & Hofkes, 2015). With these preconditions, fair results can be achieved using Hubbert Peak theory in projecting the future peak and end of production after the inflection point (midway to peak) is passed which become good results after peak production has passed (Laherrère, 2000).

The Capital-Resource, Predator-Prey Model

Another easily visualized depletion model is drawn from the multidisciplinary merging of ecology, biology and economics that compares capital/predator chasing resources/prey (Höök, 2010). This model departs from Hubbert Theory (an empirical data analysis of the lifecycle of mine and well extraction) to include the resource and capital acting as a feedback loop, affecting production (Bardi and Lavacchi, 2009). This predator-prey model as developed by Lotka and Volterra in the mid 1920s finds common origin with Hubbert's from the early 1800s logistic studies. Lotka and Volterra's model, originally created to study simple biological systems,[55] has since been found to have value when used for economics and fisheries, where resource access is unrestricted (Bardi and Lavacchi, 2009; Höök, 2010). Capital in this model is defined as the equipment, land, knowledge, labor and energy needed for extracting fossil resources: coal, gas,

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[54] A current example of political interference in resource extraction is the banning of fracking in France. Further detail can be found at: http://blogs.scientificamerican.com/observations/2011/06/30/france-becomes-first-country-to-ban-extraction-of-natural-gas-by-fracking/

[55] The predator-prey model is a poor model when used in biological studies, as it is incapable of incorporating the complexity of ecosystems into its underlying assumptions (Bardi & Lavacchi, 2009).

oil and uranium. Because capital and extraction rates are interrelated the amount of capital defines the rate of resource extraction and the lack of resource defines the amount of capital dedicated for extraction. Using the predator-prey model, a peak in the production of resources is generated like Hubbert's when resources are assumed to be nonrenewable, or are very slow in replenishing (Höök, 2010). As an economic or sustainability model, the "predator" (re: human population) is driven by the increase in profits that result from the "prey" (resource extraction and production) resulting in positive feedback, which acts in turn to increase extraction and production of the resource (Motesharrei et al., 2014). Working to restrain extraction is negative feedback resulting from a decline of high quality and most profitable resources. This model projects a peak production when the combination of energy and financial capital begins to tighten and recede (Bardi and Lavacchi, 2009).

For fossil fuel extraction, the predator-prey model points to an energy production ascent where there are high EROI energy resources to exploit, and descent when extracting lower EROI resources. Accordingly, this model predicts what most analysts are stating, that "The world will never run out of oil, rather it will run out of cheap oil that one can afford to burn" (Rubin, 2009). There will be no total exhaustion of oil and coal, rather it will no longer be of profit or value to exploit. Furthermore, the notion that production can be increased by "Drill Baby, Drill" become recognized as political and economic hubris, much like increasing the number of boats setting out to fish in a lake that is increasingly fished out. There are better ways to invest capital.

Complex Models

Simple models such as Hubbert Peak Theory and the Predator-Prey model generate a reasonable prediction of future production only under specific, controlled conditions. They both dictate a future of conventional fossil energy peak and descent but they do not include other complex factors that influence production. These factors include numerous interlinked influences, such as politics, legal changes, environmental degradation, technological improvements, limits to other needed resources for extraction. Water and natural gas for example provide the foundation of the Alberta tar sands mining operations and nuclear energy and coal that are needed for electricity generation allow continued coal mining in the Appalachian Mountains.

Complex models such as the LTG World3 model of systems dynamics accounting for multiple factors under various scenarios point to an energy production peak, and following descent, as do other models used by major agencies such as TOTAL, UK Industry Task-Force on Peak Oil and Energy Security (ITPOES) and UK Energy Research Centre (UKERC). While most believe that fossil based energy sources are finite and can be consumed once, there exist a small group of individuals who believe in adiabatic oil[56]. To these individuals, peak conventional oil is a conspiracy used to extract higher prices from people at the pumps. In general, scientists supporting adiabatic oil have little geologic background and their works have been largely rebuked (Höök et al., 2010). There is a larger population holding to the belief that human ingenuity will discover new and other sources of energy to substitute for fossil fuels. Critical examination of the growing evidence is pushing these voices of denial, disbelief and cornucopian

[56]Adiabatic Oil has a small number of followers that believe in that oil is created naturally and is not of organic origin. To extract oil, one must simply dig deep into the earth's crust.

hopes to the fringe. Peak conventional oil occurred in 2011, peak coal in 2013 and peaks of conventional gas and uranium are expected to be close behind (Ingles & Denniss, 2010; Owen, Inderwildi, & King, 2010; Maggio & Cacciola, 2012; Sorrell, Speirs, Bentley, Miller & Thompson, 2012; Chapman, 2014; Bentley & Bentley, 2015; Berman 2015; Warrilow, 2015; IEA, 2016b; The Hills Group, 2016).

Wicked Problems

Peak conventional fossil energy brings challenging questions aptly defined as wicked problems. Examples of this can be illustrated by a complexity of ethics of convenience, where the exploitation and consumption of fossil fuels bringing benefits to one global region are often derived at the expense from negative externalized costs endured by others. These negative externalities should cause us to question who benefits and who suffers from the polluted environment, climate disruption, decreased crop yields and rising sea levels (Orr, 2004; Dyer, 2009; Ackerman & Stanton, 2010, 2012; Nicholls & Cazenave, 2010; Farbotko & Lazrus, 2012; Dalby, 2014; Gemenne, Barnett, Adger & Dabelko, 2014)[57]. It is the extraction of controversial forms of fossil energy such as bitumen mining, reframed as tar sands oil extraction,[58] and the tight oil and gas extraction from fracking shale, limestone and sandstone, where North Americans encounter regional

[57] The ethics of this can be looked at as the profits grown from conflicts of "Accumulation by Dispossession" and/or "Accumulation through Contamination" which are witnessed in regions throughout the world (Pellegrini, 2012).
[58] More lately being spun as ethical oil with statements such as "The U.S. has a decision to make ... Do they want to import oil from Canada or get conflict oil from OPEC nations?" Robert Jones on August 25, 2011, as acting spokesperson for TransCanada in promoting the Keystone XL pipeline for Alberta tar sands production to reach the Gulf of Mexico (Oil Change International, 2011).

public health issues such as soaring cancer rates from the toxicity inherent to the extraction processes, contamination of fresh water, and earthquakes for those unfortunate enough to be living over or near these resources (Hatch & Price, 2008; Carter, 2010; ENVI, 2011; Jackson et al., 2014; Casey et al., 2016). These negative externalized costs are hidden and confused through a collusion of government and corporate interests (Bowen, 2009; OCI, 2011; Brulle, 2013; Sobel & Graefe-Anderson, 2014; Cann, 2015), using tactics that seem to be taken from the pages of the tobacco companies in fighting the scientific discoveries of the dangers of cancer related to smoking during the 1960s and 1970s (Donaghy et al., 2007; Bowen, 2009; Anderegg, Prall, Harold & Schneider, 2010; Banerjee et al., 2015; Bromley-Trujillo, Stoutenborough & Vedlitz, 2015).

Black Swan Events

Fossil energy literacy should contain recognition of environmental black swan[59] events that affect oil supply production, such as the public reaction to the Santa Barbara oil spill[60] in January

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[59] Black Swan derives from a Latin expression “rara avis in terris nigroque simillima cygno" that translates to "a rare bird in the lands, and very like a black swan" (Phuvel, 1984). This expression was common in 16th century London to mean something that was impossible, later evolving to an impossibility that could be disproven, from the 1697 discovery of the existence of Black Swans in Western Australia. Black Swan events are expected to lie outside of human experience, carry significant impact upon occurring and to understood as predictable afterwards as in, “we should have seen this coming” (Taleb, 2010).

[60] Credited in the creation and origin of numerous outcomes:

- A broad-based, environmental movement leading to the creation of the first Earth Day in 1969.
- Get Oil Out (GOO) collecting 100,000 signatures for a petition to ban offshore drilling and the State Land Commission banning offshore drilling till the Reagan government.
- The first Environmental Studies program was started at UC Santa Barbara and the Environmental Defense Center was founded.
- President Nixon signed the National Environmental Policy Act of 1969 was signed by President Nixon which led to the creation of the Environmental Protection Agency, the summer of the next year.

29, 1969 (Clarke and Hemphill, 2002), the temporary ban of drilling in the Gulf of Mexico following the Deepwater Horizon Macondo blow out in April 20, 2010 (McAndrews, 2011). Geopolitical black swan events exemplified by the Arab oil embargo that started October 17, 1973, the Iraqi invasion of Kuwait in the August 2, 1990, and the Arab Spring revolution in the overthrow the Gaddafi government of Libya that began February 15, 2011 correlate with economic recessions in the western nations (Hamilton, 2011). The loss of Libyan oil was considered by some to illuminate the limits of Saudi ability to supply fossil fuel into the global market, whose reserves remain a closely guarded Saudi State secret (Simmons, 2005; Owen et al., 2010; Tverberg, 2011b; Nakov & Nuño, 2013).

Post-Normality

Post-normality[61] arises when trying to understand the impact of peak energy using the ontological framing of historical exponential fossil energy growth. Current attempts to increase growth in fossil fuels have spilled into a strongly contested arena that will decide the fate of humanity, ecosystems, economies and globalization[62]. It can be argued that the industrial civilization is currently in the midst of global transition into a post-normal world where crises manifest themselves in the form of resource limits (Meadows et al., 2004; Rockström et al.,

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- The California Coastal Commission was created and retains extensive control over human activities that have the potential to impact California's coastal areas.
- These and other outcomes can be found in Clarke, K., and Hemphill, J (2002).

[61] Silvio Funtowicz and Jerry Ravetz developed the concept of post-normal science in the mid 1980s. Its origin is from risk management and controversies stemming from nuclear energy safety (Funtowicz & Ravetz, 2003).

[62] One only must explore the ongoing saga of oil, gas and coal funded think tanks and political movements to observe a web of fingerprints attempting to discredit climate and environmental scientists. Scientific based organizations that have formed in reaction to this assault can be found at: http://www.desmogblog.com/ and at http://ucsusa.org/

2009; Turner 2014, 2015), population overshoot (Diamond, 2005; Barnosky et al., 2016), acidic ocean and deoxygenation (Rockström et al., 2009; Long, Deutsch & Ito, 2016), five different continent sized ocean floating plastic dumps (Moore, 2011), climate change (Rockström et al., 2009; Hansen et al., 2016) and declining net energy (Murphy and Hall, 2011a, 2011b; The Hills Group, 2016). The uniqueness of the post-normal world is that historical risks that emerged in previous eras were regional in scope, which are contrasted to contemporary risks that are global, impacting all humanity, and presenting themselves as crises in forms that industrial civilization and humanity has never experienced before. Peak fossil energy is one such challenge as it is the transition out of roughly a one hundred fifty years of carefree uninterrupted exponential growth using various fossil fuels[63] which enabled the creation of our current globalized civilization. This unprecedented fossil fuel sourced growth period is currently peaking and about to head into decline, and humanity must learn to redesign a civilization different from the industrial civilization that grew up with seeming unlimited amounts of energy (Tainter and Hoekstra, 2003; Wells, 2007; Heinberg & Lerch, 2010; Heinberg, 2012a, 2012b; Kumhof & Muir, 2014; Matsumoto, Voudouris & Andriosopoulos, 2014; McGlade & Ekins, 2014; Turner, 2015).

The LTG report while not predicting the future, outlined various pathways the future could take (Nørgård et al., 2010; Bardi, 2011; Turner 2014, 2015). Central to resource depletion and rising pollution outlined in the LTG model is a need to understand the role of fossil energy. Chapter three works to clarify the confusion relating to fossil energy production stemming from the

[63] Nashawi, Malallah and Al-Bisharah (2010) identify the acceleration in oil consumption to correlate with the invention of the internal combustion engine.

multitude of terms, definitions and measures used around the world and enable a better overall understanding in the depletion of the quality fossil fuels that are being produced and consumed.

Chapter Three

Fossil Energy Metrics: Understanding the Conversation

> Some problems are so complex that you have to be highly intelligent and well informed just to be undecided about them (Laurence Peter, Peter's Almanac, 1993).

After conventional oil's peak in 2011, anyone searching online for global or world energy consumption[64] will find something along the lines of 540 exajoules (EJ)[65] of energy was consumed on average each day[66] or in 2014 most energy was supplied through an average daily consumption of 88.7 million barrels of oil (conventional and nonconventional)[67], 3882 MTOE of coal and 120 trillion cubic feet of natural gas. These types, numbers and units of measure are beyond ordinary experience and as such are confusing to most readers[68]. Unless the reader can contextualize and make sense of the numbers used in energy circles or simply knowing what to search for on the internet, conversations about peak conventional oil, gas and coal do little to inform them about what is happening, except that numbers involved are incomprehensible. One can argue the enormity of these numbers actively disenfranchise the average person from

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[64] The most recent summary of global energy consumption can be found in World Energy Outlook (WEO) yearly updates (generally released in November) from the IEA. Further detail can be found at: http://www.worldenergyoutlook.org

[65] 541 exajoules (EJ, means x 10^{18}) equals 0.541 zetajoules (ZJ, means x 10^{21}).

[66] Source British Petroleum (n.d.). BP Tools. Further detail can be found at: http://tools.bp.com

[67] Oil generally has two measures to it: Conventional oil which plateaued between 80-85 million barrels each day from 2004 to present and unconventional oils such as tar sands, coal synthetic fuels and natural gas liquids such as propane, ethane and butane. These synthetic fuels are substitutes for oil and count towards the total liquid fossil fuels numbers (LFF) that one observes in current supply increases of today.

[68] IEA maintains an online energy converter that will help in converting energy units to a standard measure. Further detail can be found at: https://www.iea.org/statistics/resources/unitconverter/

attempting to understand energy debates, simply because the numbers involved are far outside one's personal experience. It seems likely that the average individual would see the issue through a personal consumptive lens; such as discussing gasoline prices instead of future widespread fossil energy shortages. It is unfortunate that misconceptions over rising gasoline prices are exploited and exacerbated by various interests that undermine public discourse surrounding of the current peak fossil energy plateau[69] and projected impact of net energy descent (Martenson, 2010; The Hills Group, 2016). Peak conventional oil, typically framed as a production metric, is the measure of the maximum volume of oil pumped out and refined for industrial civilization to consume. The standard measure of this volume is that of a barrel (bbl)[70] [71], where the industrial civilization used at peak a little over eighty-five million conventional barrels of oil each day (85.3 MMbpd), the rough equivalent of thirty-billion barrels per year (30 Bbpa).

A Cubic Mile of Oil

Hew Crane, while waiting in his car at a U.S. gas station line in 1974 for his ration of gasoline during the Arab Oil Crisis, questioned how to better comprehend the global magnitude of millions and billions of barrels of oil used, he determined that relating it to a "cubic mile" of oil or a CMO would be useful (Crane, Kinderman and Malhotra, 2010). The convenience of this metric is that it is far easier to understand impending conventional fossil fuel shortages. Current yearly conventional oil consumption has climbed to a little over one cubic mile, but there are

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[69] Peaks do not have to have to be pointy.
[70] One barrel of oil (1 bbl) equals 42 U.S. gallons or 158.9873 litres.
[71] The 42-gallon oil drum can trace its legacy back to King Richard III who standardized the sale of wine in 84 gallon (puncheon) and 42 gallon (tierce) casks. With a fully filled tierce being at the limits of what a man could move around, it became the most common barrel of measure for shipping numerous fluids (AOGHS, 2006).

only around forty-three cubic miles of proven oil reserves[72, 73] left on Earth. Crane extended this to the other fossil fuels, since humans burn 0.8 CMOpa equivalent in coal with eighty-nine CMO of coal left in reserves and 0.6 CMOpa in natural gas with reserves of forty-two CMO (Rutledge, 2011). The remaining large sources of consumed energy are biomass (0.19 CMOpa), hydroelectric (0.17 CMOpa) and nuclear (0.15 CMOpa), with geothermal and remaining renewables accounting for less than 0.01 CMOpa. In total, the industrial civilization uses around 2.99 CMOpa of energy, where 2.63 CMOpa comes from fossil fuel sources. Only twelve percent of all energy consumed globally, can be classified as renewable (see Figure 3.).

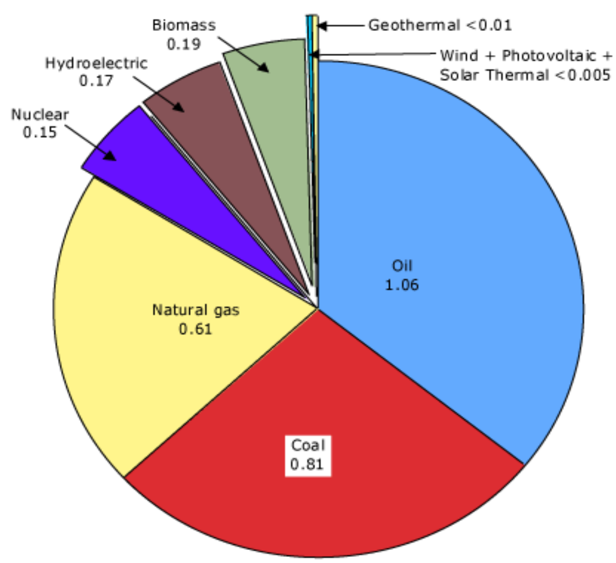

Figure 3.1 Global Energy Sources in 2006 in CMO
(Source: Crane, Kinderman and Malhotra, 2010)

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[72] For organic sourced fossil fuels: 1 CMO = 4.17 CKO cubic kilometers of oil = 26.2 billion barrels of oil = 4.6 billion tons anthracite (black coal) = 8.5 billion tons lignite (brown coal) = 150 trillion cubic feet of natural gas.

[73] For physical energy content: 1 CMO = 44.5 trillion kWh = 153 quads BTU or 152 quadrillion BTU's.

Crane's reduction of all energy sources to the metric of CMO, brings simple counting numbers to the energy debate and a level where all can participate. However, there remains a substantive problem of numeric conversion that is needed to standardize all different measures in the energy world to a common metric of a CMO. In Canada and the United States[74], coal is measured in short tons, long tons or tonnes[75] and global reserves are measured in the hundreds of billions of short tons. Natural gas is measured in cubic meters (m^3) or cubic feet (ft^3) and global reserves measure in the thousands of trillions of cubic feet. Natural gas is sold to customers in Canada and the United States in various forms, therms (th), British Thermal Units (BTU), hundred cubic feet (Ccf), thousand decatherms (MDh) or million decatherms (MMDth) and gigajoules (GJ). Working with these measures requires conversion tables and a calculator to simply manipulate and understand the energy needs of a household or a business (Karbuz, 2004). Crane's CMO metric removes trains of zeros, needing only basic arithmetic to understand the global picture, making it ironically easier than trying to calculate the energy consumed in one's home.

In using Crane's CMO metric, the post-normal world of net energy descent defined by the turbulent[76] supply plateau and ensuing production collapse, is one where industrialized

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[74] There is no standardized global measure of fossil energies. Instead one finds that units, measures and definitions are unique to different regions and nations leaving many global measures of fossil energy as estimates and vary differently between different agencies.
[75] Canada and the United States use both short tons (remnant of the English measurement system), equaling 2000 pounds and the long ton (tonne, metric ton) is the metric measure of 1000 kilograms or 2240 pounds.
[76] The extent of the price drop of oil prices in August 2014 caught forecasters by complete surprise with Consensus Forecasts indicating that none of the 700 economists they polled had predicted it (Husain et al., 2015).

civilizations must move from a global consumption of 3 CMOpa of energy to 0.4 CMOpa[77] in the space of one or two generations. The energy descent is steep, where the supply of conventional produced oil[78] having already peaked in 2011 at around 85-86 MMbpd is expected to begin a steady but certain decline of an expected 6.7% by 2015 (IEA, 2011[79]).

Net Energy = Energy Produced - Energy Invested

EROI and Net Energy Metrics

Peak oil production by volume, is a misleading metric when trying to understand coming changes. The quality of energy supplies yields a more accurate picture of its plateau and following descent, using EROI[80] (EROIE) and Net Energy[81]. Oil production, when measured by the volume produced, does not account for the energy (oil, gas, coal, resources, equipment and other energetic sourced inputs) expended to search for, dig up, refine and transport the finished oil products to where they are consumed. Energy gained can be explored in many ways other than from Net Energy and EROI (a blend of economic /physical science perspectives) but these

[77] One must qualify this the 0.4 CMO future by noting the potential of renewables or other alternate energy sources to increase this number and one should be cautioned to expect this to increase, outside of various agencies working to hinder the transition to renewables.
[78] Oil is unique among the fossil fuels as it is considered the lifeblood of transportation, and as such is the foundation supporting globalization (Rubin, 2009, 2012; The Hills Group, 2015).
[79] The IEA (2010) World Energy Outlook used the word “Peak” for the first time in its report and raised the projected decline rate from 3.7% to 6.7% in its study of the 800 world’s largest oil fields.
[80] EROI is the ratio measuring the energy produced compared to the energy that is used to extract energy. When EROI less than 1, it means that it takes more energy to produce than is gained.
[81] Net Energy or Net Energy Gain, is a physical science measure of the benefit of an energy source, where the energy that is gained is subtracted from the energy it took to obtain. When Net Energy is zero or negative, then it is an energy loss to use.

two stand out due to their utilitarian value (Cleveland, 2005; Gagnon, Hall & Brinker, 2009; Hall, Balogh & Murphy, 2009; Murphy, D., 2009; Brandt & Dale, 2011).

EROI's origin can be traced to Charles Hall's Ph.D. dissertation (1970) at University of North Carolina (UNC), where as a graduate ecologist, he explored the biophysical relation between the energy expended by predators and energy returned through consumption of prey (Hall and Klitgaard, 2012). Hall's earliest interest was in the migration of fish, questioning why parents from numerous species would expend large amounts of energy to migrate great distances

$$\text{EROI} = \frac{\text{Energy delivered to Society}}{\text{Energy expended (Produce \& Deliver above Energy)}}$$

$$\text{Net Energy Returned} = [\text{Total Energy Produced}][(\text{EROI} - 1) / \text{EROI}]$$

upstream to spawn. This paralleled his second interest in the impetus behind salmon smolts leaving the safety of their spawning grounds to also travel great distances, such as the mouth of the Fraser River in Vancouver, BC to feeding grounds in the Alaskan Aleutians (Nikiforuk, 2011). In both cases, the spawning and feeding grounds were rich for nutrients and food meaning that it required less energy for the fish to find food. The discovery of energy surplus as a central force in aquatic life led Hall to study the biophysical links between surplus energy and civilization (Nikiforuk, 2011). EROI and Net Energy eventually became two useful metrics to quantify this surplus energy that arose from these original biophysical queries (Mulder and Hagens, 2008). EROI quantifies the amount of new energy obtained in a ratio to the original amount of energy expended to obtain this energy, much like the economic return on investment, (ROI) in an economic cost benefit analysis (Murphy, Hall, Dale & Cleveland, 2011). The major differences between energy and standard business economics is that energy returns are in the hundreds and thousands of percent, rather than the single to double digit percentages commonly associated with investments such as bank interests or stock prices. EROI is given as a ratio such as 100:1, 20:1 or 3:1, meaning that either one hundred, twenty or three units of energy will be returned to every one used to obtain that new energy.

Metaphorically, EROI can be related to a bang for the buck multiplier effect while Net Energy relates to the energy profit that one gains after subtracting all the energy costs. Differences between these two metrics are simply illustrated: an EROI of 40:1 is a great return of energy for an energy production facility, but one must consider the scale or magnitude of operations to understand the total energy that one has gained from this. For instance, is the final production a truck or a super tanker of oil? Net Energy, while presenting the total amount of energy obtained from an energy production process, needs the EROI metric to illuminate the efficiency: 1.2 million barrels of oil recovered from an operation that used 1.1 million barrels of oil to produce, means an 8% gain and an EROI value of 1.09:1. Used together, one gets a rate of return (EROI) and the magnitude of the return (Net Energy).

EROI can also be used to measure the energy success rate of energy exploration. In the 1930s, oil exploration had success rates of EROI returns of 100:1, as oil was nearer the surface and comprised higher grades that were easier to refine (Cleveland, Hall, Hallock, Jefferson, & Tharakan, 2003). As one drills, deeper, oil grade declines[82, 83], becoming more viscous, manifesting in a considerably lower EROI. Using these measures, one can critically explore the energetic value of "Drill Baby, Drill" as expressing either an actual solution to supplying energy for future use, or spending more energy for increasingly marginal energy returns. Basic market economics suggest that the most profitable resources, the ones most accessible with the highest EROI and Net Energy were probably drilled and exploited first (Holditch, 2006; Brierley, 2007; Tverberg, 2016). Industrial civilizations are now left with the less profitable resources (as shown in Figure 3.2) to extract, and as such both EROI and Net Energy benefits to civilization are declining (Murphy & Hall, 2011a; The Hills Group, 2016).

[82] The highest grades of oil and gas formed under heat and pressure (in some ways like what a refinery does) migrate up through porous rock until becoming trapped by formations that act as an impervious barrier preventing further migration. As such, these highest grades are generally the first encountered when drilling a well that penetrates this barrier.

[83] "Simply put, rationally-acting human populations will first exploit those resources that yield the best return per unit of effort, and still meet the needs of the population. If this is so, then it follows that any change in resource extraction must be in the direction of using resources that are costlier to obtain, process, distribute, and/or market, so that the marginal product of labor and other inputs declines" (Tainter, 1990, pp. 110).

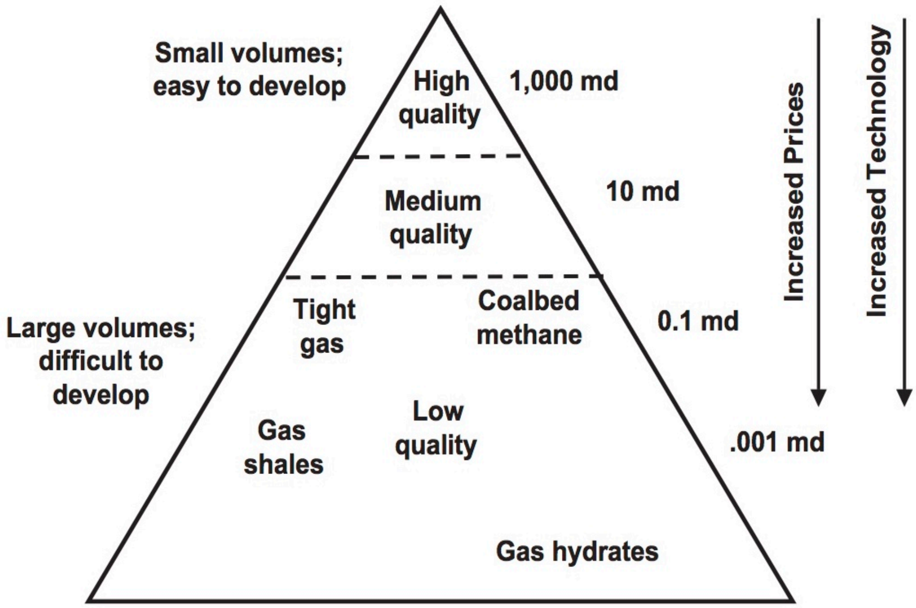

Figure 3.2 An illustration of the resource triangle model for natural gas extraction with natural gas flow permeability units given is millidarcies (md) where 1 darcy ≈ 10^{-12} m^2 (Source: Holdich, 2006)

When using EROI or Net Energy to critically explore a front-page announcement about a 900-million-barrel pool of oil found off the coast of Brazil or Greenland, one can discern from the amounts used daily that this discovery will run the earth for a little over ten days. The finer detail of this energy benefit emerges only after accounting for the energy expenditures to build a deep water oil rig, drill down through the miles to the ocean floor, and transport this oil by tanker to the refinery, where energy is used to heat and process the oil into various products before its final delivery to the consumer. This expended energy must be subtracted or divided from the nine hundred million barrels. As such, the EROI value of a 900-million-barrel pool can be reduced to 2:1 or less, which is not a substantial rate for energy return, and represents approximately five days of industrial civilization's consumption.

Despite the benefits of using EROI and Net Energy metrics, one problem that plagues them stems from defining the boundaries of energy expended in production. The lack of a convention defining these boundaries results in significant variability in the EROI and Net Energy outcomes for the same finished product (Mulder and Hagens, 2008; Murphy, Hall & Powers, 2011; Tello et al., 2015). Energy expended to gain more energy is broken into two parts: direct energy used from all fuels or other energy sources on the production site, and indirect energy that is embodied in the equipment and other materials used (Murphy et al., 2011). Furthermore, contested boundaries arise from addressing questions such as: Does one account for negative externalized costs, such as environmental cost resulting from CO_2 emissions and oil spills? Should one account for the energy costs of laborers working in the production process and the energy they consume as they spend their wages that have been earned from the energy production to support their lives (Mulder & Hagens, 2008; Murphy et al., 2011)? Even with the above simple examples, these underlying boundary issues are ones that cause confusion in looking at the compiled results of EROI studies. Furthermore, while capitalist economics currently dominate decisions about the energy production from the perspective of a profit framework, it can be strongly argued that EROI and Net Energy are what define the ultimate value of energy to civilization (Hall et al., 2009; Murphy et al., 2011; Murphy & Hall, 2011a, 2011b).

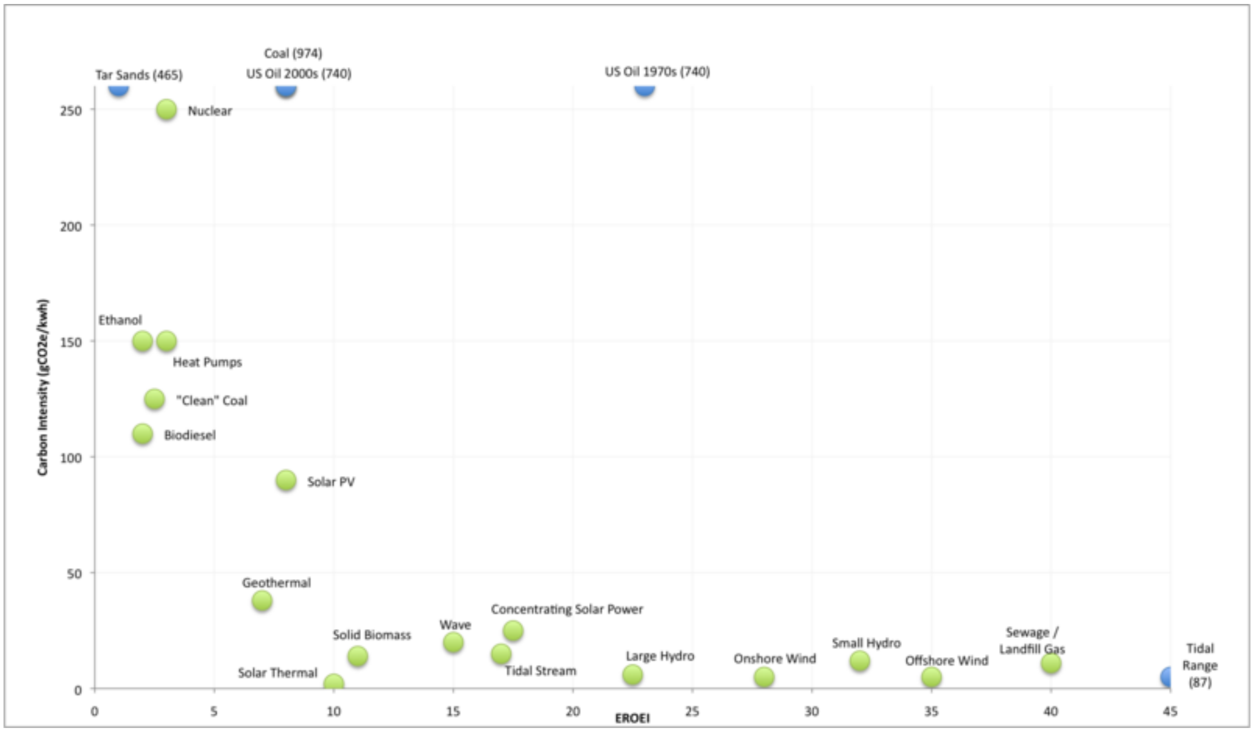

Figure 3.3 Carbon Emission standardized by per kilowatt-hour compared to EROI of source (Source: Robinson, 2009).

Robinson (2009) illustrated in the above graph (Figure 3.3), the comparison of the EROI from various fossil fuels to the externalized cost from the carbon emissions they emit, expressing that various fuels separate into three general classification of CO_2 emitters. Using his analysis, tar sands, nuclear, coal and oil are the worst emitters, biofuels, biodiesel, clean coal, heat pumps and solar photovoltaics are mid-range emitters, with the remaining sources of energy on the bottom of the graph acts as lowest CO_2 emitters.

Fossil fuel energy, comprising oil, gas, coal and nuclear, all have limits of what might be recoverable due to EROI and Net Energy realities. When considering the economic[84],

[84] Tverberg (2011a) takes the economic position of supply vs demand, where the lack of demand for high priced oil is the main factor holding down increased production.

environmental, geological, political and accessibility issues, there remain complex lines drawn beyond which fossil fuels might never be recovered or used. The end of the oil age will come not when all the oil is used, but rather when a limit has been reached where it does not make sense to further exploit that fossil resource (see Figure 3.4 for various estimates of declining EROI for global oil production), or as some have phrased, “the stone age did not end for lack of stone” [85]. This becomes in part the challenge of trying to understand peak net energy: to navigate through what is known about the limits of fossil fuel resource extraction and how these resources will

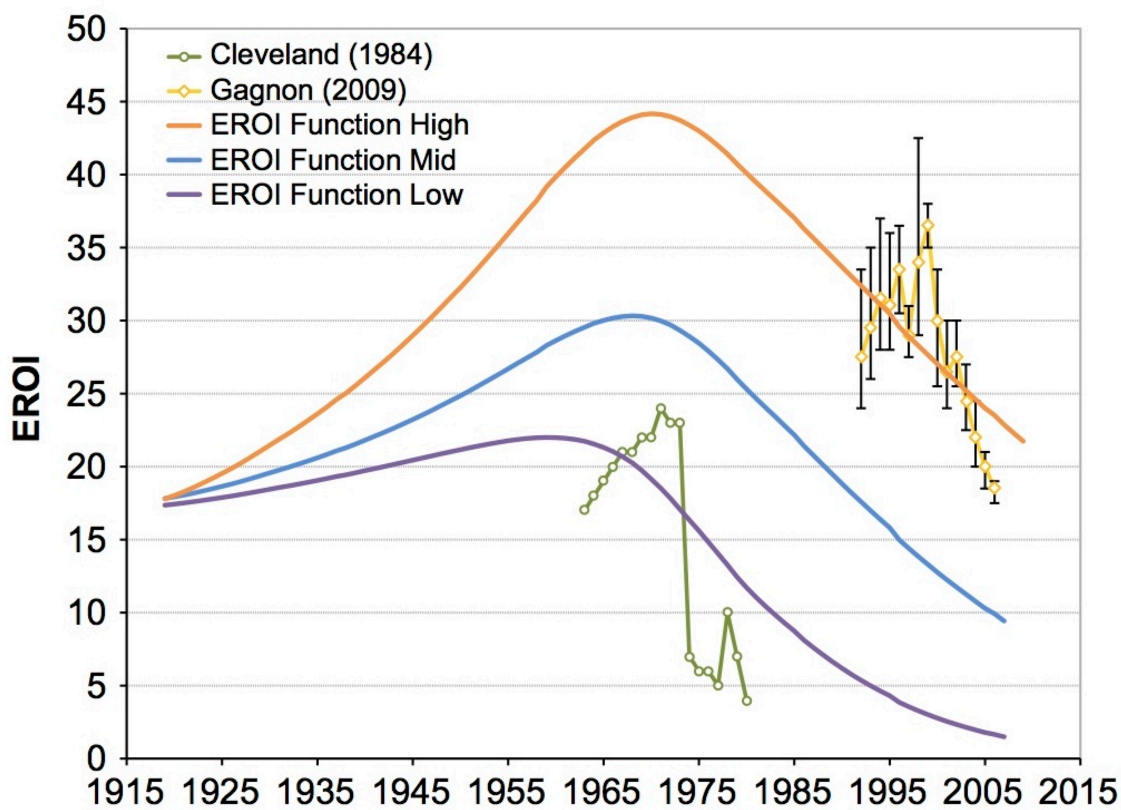

Figure 3.4 Average modeled EROI function showing the estimated High, Mid and Low EROI returns of Global Oil Production (Source: Dale, Krumdieck & Bodger, 2011)

[85] Sheikh Zaki Yamani (Former Saudi Oil Minister) quote: The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil (The Economist October 23, 2003).

cease to be of value as an energy source. Once the EROI of fossil fuel extraction is less than one, continued extraction will only continue only if it is a fuel of convenience.

Oil and Natural Gas Supply and Reserves

There exists no common or standard metric for the different ways the oil and gas industry classify unrecovered oil and gas outside of guidelines prescribed by the World Petroleum Council[86] and the Society of Petroleum Engineers.[87] This explains polarized views on conventional oil reserve status from agency failure to use standard metrics (Owen et al., 2010). A simple definition of reserves is that they represent all that is known and can be classified as recoverable under current economic conditions (Jakobsson, 2012). Reserve measures are not static and change as the petroleum is removed from the ground. The first estimate is called an Ultimately Recoverable Reserve (URR)[88] which is in essence an educated guess of how much of the petroleum might be extracted. Standard percentages of oil that can be extracted vary from as little as 10% to a high of 80% (Höök, 2010), with an estimated average of 29%, and with technological improvements, reaching as high as 38% (Meling, 2005). Under this metric, an average 62-71% of all known petroleum resources will remain in the ground, unable to be extracted with current technology.

[86] World Petroleum Council (WPC) home link can be found at: http://www.world-petroleum.org/index.php?/Reserves-Resources/reserves-a-resources.html
[87] Society of Petroleum Engineers (SPE) home link can be found at: http://www.spe.org/industry/reserves.php
[88] URR is the percentage of petroleum that can be recovered is the product of the Recovery Factor (RF) of the Petroleum in the Ground, PIIP. One only knows the final measure of the URR, when the reserve is exhausted and no more petroleum is extracted.

URR can be either a deterministic or a probabilistic estimate of the commercially recoverable oil and one will run into terminology such as P90, P50 or P10 or 1P, 2P and 3P when considering these estimates. These metrics correspond to each other in the following manner:

> Ultimately Recoverable Reserve = (Petroleum in Place) x (Recovery Factor)
>
> or
>
> URR = PIIP x RF
>
> Petroleum in Place (PIIP) is also: Oil Initially in Place (OIIP)
> Oil Originally in Place (OOIP)
> Oil in Place (OIP)

1. Lowest: P90 means that there is a 90% chance of recovering more petroleum than the estimate of URR given. It is the low-ball estimate that should be exceeded. This is roughly equivalent to the low estimate of 1P (proven) reserves.

2. Median: P50 is the median estimate of what might be recovered of the URR, where the chance of exceeding it is 50%. This midrange estimate corresponds to the 2P metric (proven + probable) reserves.

3. Highest: P10 is the highest estimate of URR, where the chance of exceeding it is 10%. This highest estimate corresponds to 3P (proven + probable + possible) reserves.

Petroleum in the Ground is divided into two types, discovered and undiscovered, and the petroleum is then further classified as unrecoverable, prospective, contingent or using the above reserve classification as proved, probable and possible. PIIP includes undiscovered reserves which are an estimation of the potential oil and gas that will be added to existing reserves within thirty years and contingent reserves that have been discovered but are classified as commercially unrecoverable (see Figure 3.5). Estimation of prospective reserves is accomplished using a Monte Carlo simulation[89] which uses extensive sampling and accounting for geologic and access risks, enabling a probability distribution of what remains to be discovered (Brown, Protano & Ulgiati, 2011). Of significant concern is that what remains to be discovered are increasingly

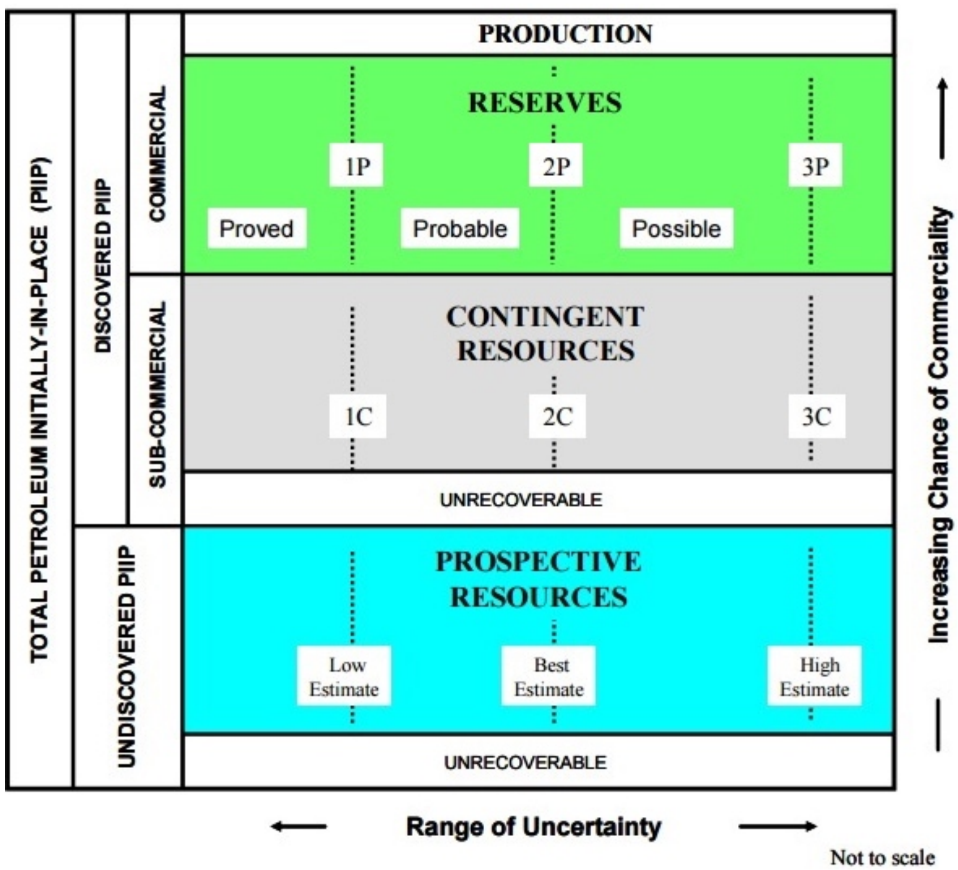

Figure 3.5 PIIP Resource Classification Framework (Source: Purewal, Ross & Rodriguez, 2011)

[89] Monte Carlo Simulations came to prominence in the late 1940's from nuclear weapons research at the Los Alamos National Laboratory where investigating a neutron's travel through shielding was unsolvable using deterministic methods. The resulting solution of using the Monte Carlo Simulation where a computational algorithm uses randomness to solve for deterministic problems has generated a reputation for its usefulness in solving difficult or impossible to solve mathematical and physical problems.

smaller fields and not the giant fields[90, 91, 92] that have been prominent in global energy supply. Two watershed events that have already passed are: first the peak discovery of conventional oil and gas fields in 1968 which has been declining ever since, and second in 1981 where the discovery of deposits increasing URR have fallen below the rate of conventional oil and gas production (see Figure 3.6).

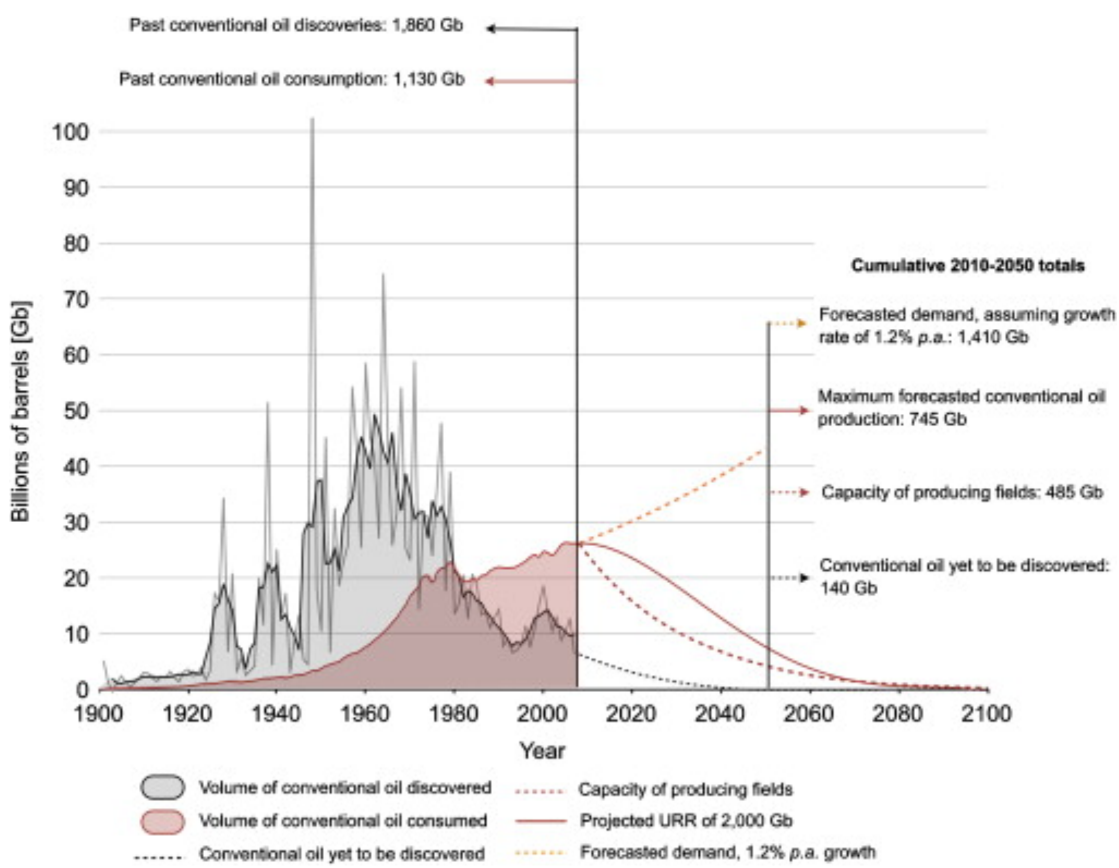

Figure 3.6 Global Conventional Oil Discovery and Consumption: actual and projected for the years 1900 to 2100 (Source: Owen et al., 2010)

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[90] Giant fields have an URR greater than 500 million barrels or a peak daily production that exceeds 100,000 barrels. More than half of all the URR comes from this fraction of fields and as of 2005, over half of all global oil and gas production came from them (Robelius, 2007).

[91] Fields are generally classified as either OPEC/Non-OPEC and onshore/offshore as these distinctions bring unique features of development, production and decline.

[92] "The discovery rate for new oil and gas fields over the last two decades (with the possible exception of Brazil) provides little reason for optimism that future efforts will find major new fields."(Mattis, 2010).

Contrary to what one might expect from diminishing results of exploration and discovery, URR has been increasing from a phenomenon termed reserve growth (Sorrell et al., 2012). Factors working to growing the reserves are geological, technological and the reclassification of URR through upgrading reserve estimates from 1P to 2P or 3P (Thompson, Sorrell & Speirs, 2009). Geological reserve increases are obtained mainly through an improved knowledge of formations, rock porosity, and accuracy over the size of the reservoir[93]. Technological improvements in better extraction techniques, such as the fracking process that allows one to extract oil and gas from shale formations[94], acts to move reserves from possible or unrecoverable, to probable or possible. Upgrading the reserve estimate grows from experience and knowledge in extracting petroleum specific to a particular field[95] or reservoir[96] and thus the initial conservative and approximate estimates become more realistic over time. All three factors act to increase the amount of reserves, but uncertainties in how these factors manifest for each individual reserve make prediction of reserve growth near impossible (Jacobsson, 2012).

In 1984, five major OPEC producers changed their definition of proved reserves from P90 to P50 which resulted in OPEC URR increasing by 80% with Iraq, UAE and Venezuela increasing their reserves threefold as shown in Figure 3.7 (Sandrea, 2003; Jefferson, 2016). These increases

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[93] Seismic imaging from sound wave reflection off underground formation allows estimation of the depth and structure of geologic formations. Sophisticated 3-D surveys show a reservoir at various stages of depletion allowing for improved recovery. Source Chevron (2015). Further detail can be found at: https://www.chevron.com/stories/seismic-imaging

[94] Oil extracted from shale formations is classified as tight oil. Tight oil is often confused with oil shale (kerogen) that more closely resembles coal where heat must be added to finish the "cooking process" to turn oil shale into oil. Tight oil and shale oil are two different types of hydrocarbons extracted from shale formations.

[95] A field refers to a region of one or many reservoirs of oil and gas that share the same geologic features.

[96] A reservoir refers to an individual pool or body of trapped oil or gas accumulation.

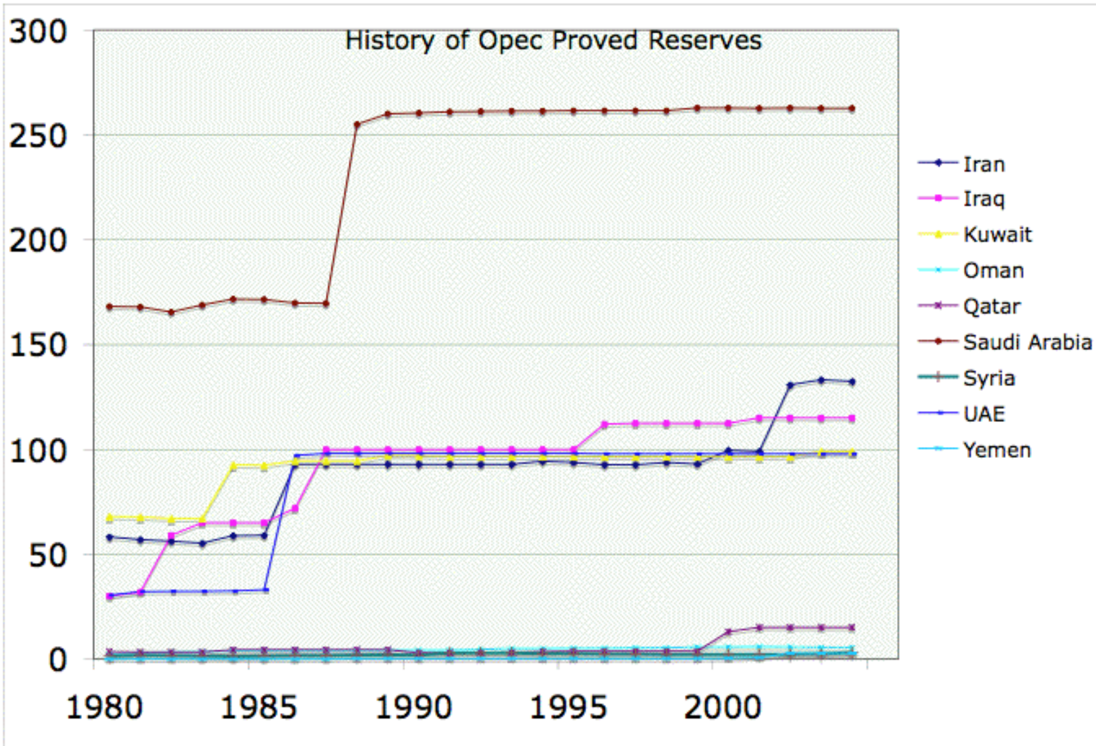

Figure 3.7 Starting in 1984, the five largest OPEC exporters changed their definition of proved oil reserves from 1P to 2P, generating a boost of global URR of nearly 435 bbl (Jefferson, 2016) (Source: Staniford, 2006)

led to oil industry controversy over suspicion that the URR increases were grounded in the attempt to increase the member share of the finalized 1986 OPEC quota agreement on oil production, when quotas were established to stabilize oil production at an amount designed to be fair and reasonable to both producer and consumer (Salameh, 2004; Chalabi, 2010). The 1986, quota one of many in a series of attempts to create a stable system among OPEC members, was based on two metrics. One was oil based-reserves, production capacity, historical production share, domestic oil consumption, and production costs and the other socioeconomic-population, dependence on oil exports and external debt (Sandrea, 2003). With the importance on reserves to each member's export quota, OPEC members treat their reserves as state secrets that many outside OPEC treat as substantially inflated or suspect (Salameh, 2004; Simmons, 2005; Rubin, 2009; Crane et al., 2010; Owen et al., 2010; Hallock, Wu, Hall & Jefferson, 2014; Jefferson, 2016). Combining evidence of the reclassification of OPEC reserves doubling around 1984-1985, holding a near flat plateau despite extraction and export, and the inclusion of a similar amount from Venezuela heavy oil and Alberta tar sands, Jefferson (2016) believes that global proved reserves of conventional oil is closer to 875 billion barrels instead of a stated 1.7 trillion barrels.

Unconventional Liquid Fossil Fuels

Unconventional liquid fossil hydrocarbon sources range from solid (bitumen, coal to liquid), and liquid (shale oil, tight oil, extra heavy oil, deep water oil & biofuels) to gaseous (natural gas liquids & lease condensates[97]) where all are significant, valuable sources of liquid fossil fuels that must be included in any conversation of reserves (Chew, 2014; Höök, Fantazzini, Angelantoni, & Snowden, 2014). While there exists no universal definition to distinguish conventional and non-conventional fossil fuels, the Society of Petroleum Engineers (SPE), American Association of Petroleum Geologists (AAPG) and the World Petroleum Congress (WPC) define unconventional or non-traditional resources that require extraction procedures outside of the traditional oil and gas well (De Castro, Miguel & Mediavilla, 2009). Murray and Hansen (2013) define quantified conventional oil as sourced from reservoirs that allow for free flow due to "sufficient pressure, porosity and permeability" and unconventional oil sourced from reservoirs without the necessary geologic structure to allow for free flow or ones that require special technology. The EIA define natural gas liquids and lease condensates as conventional,

[97] Natural gas liquids and liquid condensates while not oil, are counted in the liquid fossil fuel numbers. It is important to remember that the energy density of these liquid fuels is quite different. For instance, propane is around 2/3 the energy density of a barrel of crude (Livingston, 2014).

using a definition allowing for future migration of unconventional into conventional as changing technological and economic conditions permit (De Castro et al., 2009; EIA, 2013; Chew, 2014).

Conventional oil and gas are found in pockets under a shield of impervious rock. Under this shield is a relatively porous or permeable rock, through which the gas, oil and water can flow. Some of this rock is quite porous, such as in the Gulf of Mexico, where a meteor[98] is believed to have crashed into the Yucatán Peninsula, fracturing most of the rock to rubble where the high porosity in underlying rock has led to the highest recovery factor of any petroleum trapped beneath intact rock formations. Other oil and gas (termed tight oil and tight gas) can be found trapped in low permeability shale, sandstone and carbonate rock formations containing gas and oil (Munasib & Rickman, 2015). One common misconception can be found in conversations linking tight oil and shale oil (sometimes called kerogen oil). Shale oil is not an oil at all, rather it is the precursor to oil called kerogen and is transformed into a synthetic oil through processing or "cooking" (ENVI, 2011; Rapier, 2012).

Tight oil is extracted by a process termed fracking (hydraulic fracturing) which involves vertical drilling, then directed sideways to penetrate the shale rock. This is followed with a combination of detonated underground explosions followed by the injection of a high pressure chemical cocktail of sand water and chemicals into the drilled bore hole to scrub the rubble releasing previously trapped hydrocarbons. The practice of fracking has met with increasing resistance as publicized events of heavy usage of fresh water in water stressed areas, both surface and aquifer

[98] Evidence points to the Chicxulub crater underneath the Yucatán Peninsula as suspected cause of the last major extinction event that occurred 65 million years ago. Schulte et al., (2010).

water contamination, adverse health risks, environmental impacts and of dramatic increases of moderate earthquakes in non-earthquake regions (Boudet et al., 2014; Jackson et al., 2014; Lee, Weingarten & Ge, 2016; Sovacool, 2014a; Casey et al., 2016).

With unproved technically recoverable tight oil reserves estimated at 418 billion barrels, EIA (2014) projects tight oil global production to near 9 mbl/d by 2035 with the U.S. peaking at near 5 mbl/d around 2021 (Sieminski, 2014; Munasib & Rickman, 2015). Canada and the U.S., being the only two nations producing commercial amounts of tight oil and gas, have created a surplus of tight oil hydrocarbons in North America which when combined with conventional oil has resulted in tight oil to be sold a discount (Olsen, 2015). Transportation bottlenecks rising from the rapid growth of tight oil production have risen from the shortage of pipelines, rail or truck transport to keep up with the growth in production, all which is exacerbated by the recent bitumen spills and train disasters resulting in significant public protests, forcing the re-evaluation of all rail transport (Boudet et al., 2014; Olsen, 2015).

Natural gas liquids and lease condensates have doubled U.S. domestic production from liquids-rich natural gas plays[99] and increased proved liquid fossil reserves corresponding to greater profit from rising liquid prices (Livingston, 2014; EIA, 2015a). Lease condensate is a mixture of higher density hydrocarbons that is separated as a liquid in natural gas processing plants where the liquid is most often blended to enhance crude quality. U.S. P1 reserves stood at 3.5 billion barrels in 2014 with an extraction and production rate of 326 million barrels the same year (EIA,

[99] The term play is the preferred term by oil and gas industries to correlate to the USGS defined term of continuous-type deposits in classifying hydrocarbon reservoirs (Chew, 2014).

2015a). Natural gas liquids are a range of hydrocarbons that include liquefied gases such as propane, isobutane and butane that are not separated with the lease condensates but are fractionated and cycled out at processing plants. Natural gas liquids are currently not counted as part of any proved reserves.

Bitumen resources likely exceed 3 trillion barrels with 2.5 trillion estimated in Alberta, Canada, representing a volume double the liquid fossil fuels that industrial civilization has consumed to date (Chew, 2014). Murray and Hansen (2013) view oil company interest in extracting oil from bitumen as a clear indication that the future of fossil fuel production has been driven into marginal resources where scaling up production will mean a temporary delay in the decline of fossil fuel production and consumption.

Bitumen sands contains on average 11% bitumen and 4% water, yielding roughly two tonnes of sand & sandstone and two to three barrels of water to the extraction of one barrel of bitumen of which an average of 85% can be further extracted to create synthetic crude oil (SCO) (IEA, 2010; Chew, 2014). With bitumen's high carbon content and the difficulty in extraction and processing, the Pembina Institute estimates the GHG emissions to get one barrel of SCO to be in the range of 3.2 to 4.5 times that of conventional oil extraction (Stockman, 2013). Public reaction has grown over Alberta bitumen expansion due to three major concerns. First, the emissions from consuming bitumen sourced SCO expected from projected pipeline expansion are equivalent to adding the emissions from 227 coal plants having a lifespan of 40 years (Mckinnon, Muttitt and Stockman, 2015). Second, the byproduct of peticoke from bitumen refining has CO_2 emissions that are 5% to 10% higher when compared to the same net energy gained from burning coal, an amount equaling 35 years of consumption for 111 coal plants (Stockman, 2013). Third, is the risks resulting from the transport of diluted bitumen (dilbit), were illustrated in July 2010 by the Enbridge pipeline spill in Michigan of 843,000 gallons of dilbit making it the most expensive inland cleanup spill in North America and, by the July 2013 Lac Mégantic, Québec train derailment and subsequent explosion claiming the lives of 47 individuals (de Santiago-Martín, Guesdon, Díaz-Sanz & Galvez-Cloutier, 2015; National Academies of Sciences, Engineering & Medicine; 2016).

Extra heavy oil has the same density as bitumen[100] but has a higher viscosity and is found in a liquid state (Chew, 2014). The largest global deposit of extra heavy oil resides in the Orinoco province of Venezuela but there remains a great range of uncertainty over what amount of this is economically recoverable, yielding estimations that range from 60 billion to 652 billion barrels (Schenk et al., 2009; IEA, 2010, Chew, 2014; Santos, Loh, Bannwart & Trevisan, 2014). When combining estimated global recoverable reserves of bitumen, heavy and extra heavy oil, values range from 893 to 1085 billion barrels (IEA, 2010; Chew, 2014). IEA (2010) expect that bitumen and extra heavy oil will dominate the rise of unconventional oil production, but its growth will be tempered by negative economics rising from the cost of production and externalities from increased GHG emissions and externalized social costs.

Proved global coal reserves, estimated to be around 869 billion tonnes by the World Energy Council (WEC, 2013), represent a 115-year supply at current consumption levels but could be as much as 4 to 5 times larger due to coal companies not needing to prove long-term reserves.

[100] Bitumen is sometimes termed as extra, extra heavy oil.

While mainly used for electrical production and heating, recent research in converting coal to liquid fuel (CTL) has spiked interest in its ability to lower GHG emissions in consumption of liquid fossil fuels (Tarka et al., 2009). Historically Germany (up to 1945) followed by South Africa (from 1955) were the first to commercially convert coal into a synthetic liquid fossil fuel, mainly through a process termed Fischer-Tropsch Gas to Liquid (FTGTL) or Coal to Liquid (CTL) (Glebova, 2013). Since straight CTL processes have a high GHG emission footprint, ongoing research in coupling CTL with Coal and Biomass to Liquids (CBTL) result in GHG emissions less than petroleum derived diesel emissions. They are expensive to produce and require a price of oil greater than $86/bl to be economically competitive unless carbon taxation is applied lowering this price (Tarka et al., 2009; IEA, 2010).

Oil shales, used for centuries for heating, refer to clays, marls or carbonate sediments containing a high portion of kerogen. These are found in every oil region in the world as the source rock for most conventional oil fields (EIA, 2010). EIA (2010) estimates there is in excess of 5 trillion barrels of oil in oil shale of which more than 1 trillion could technically be recoverable[101]. The extraction of oil from kerogen commonly involves intense heat to break down the organic material to release gaseous and liquid hydrocarbons like those found in conventional oil but only small amounts of kerogen oil are currently produced due to economic, environmental and technical challenges in extracting kerogen at the depths it is generally found (IEA, 2010).

[101] The green river region in the U.S. holds approximately 80% of the technically recoverable oil.

EIA Recognition of Peak Conventional Liquids

In a spring 2009 DOE[102] meeting, the EIA released a graph (Figure 3.8) of expected future liquid fuels supply. Liquid fuels[103] are the most energy dense (outside of uranium), requiring the least amount of storage to transport for use and represent 95% of all fuel used for global transportation. By the year 2031, it is projected that conventional OPEC and Non-OPEC oil will

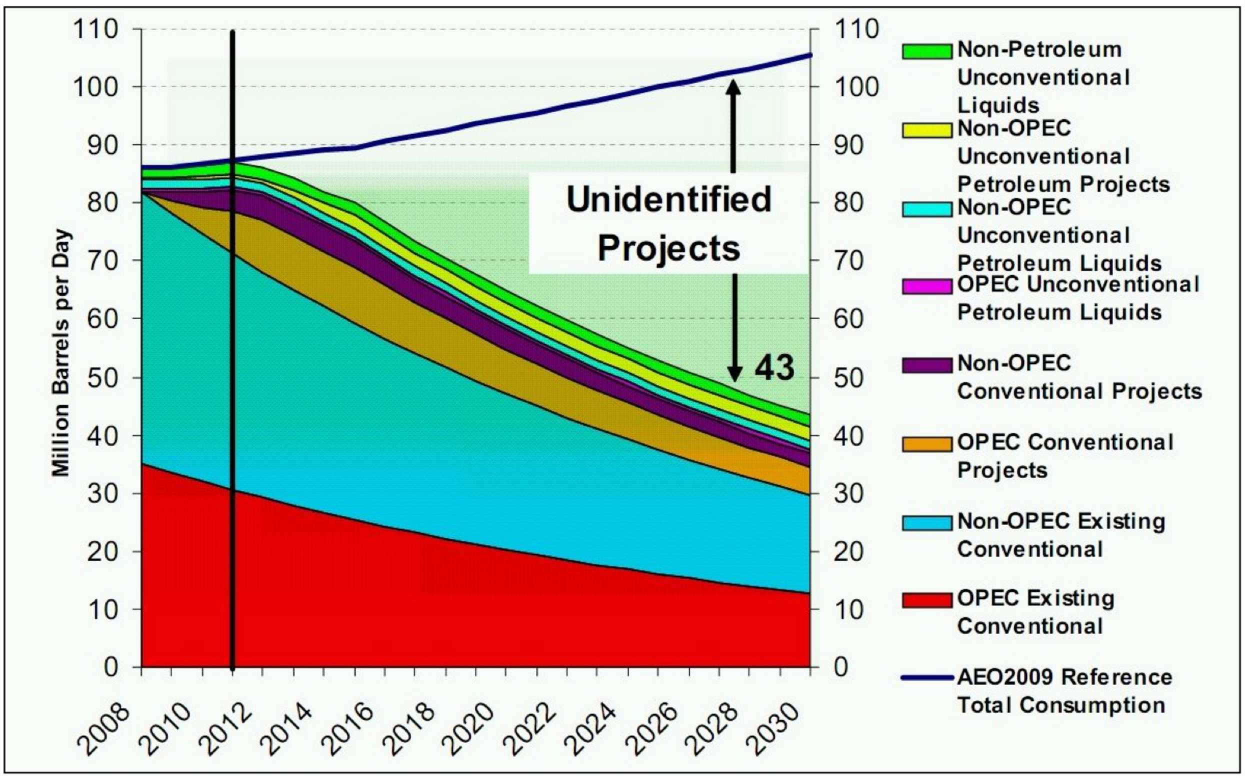

Figure 3.8 EIA Global Liquid Fossil Fuels (conventional and unconventional): actual and projected for the years 2008 to 2031 (Source: EIA, 2009)

supply less than 30% of expected global demand, when production of all identified liquid fuels drops to half of 2012 production. This shortage, displayed as "unidentified projects" (Figure 3.9

[102] United States Department of Energy - Energy.gov | Department of Energy

[103] One of the most extensive data bases of public assessable reports and papers can be found in the oil drum archives. Further detail can be found at: http://www.theoildrum.com/node/7191

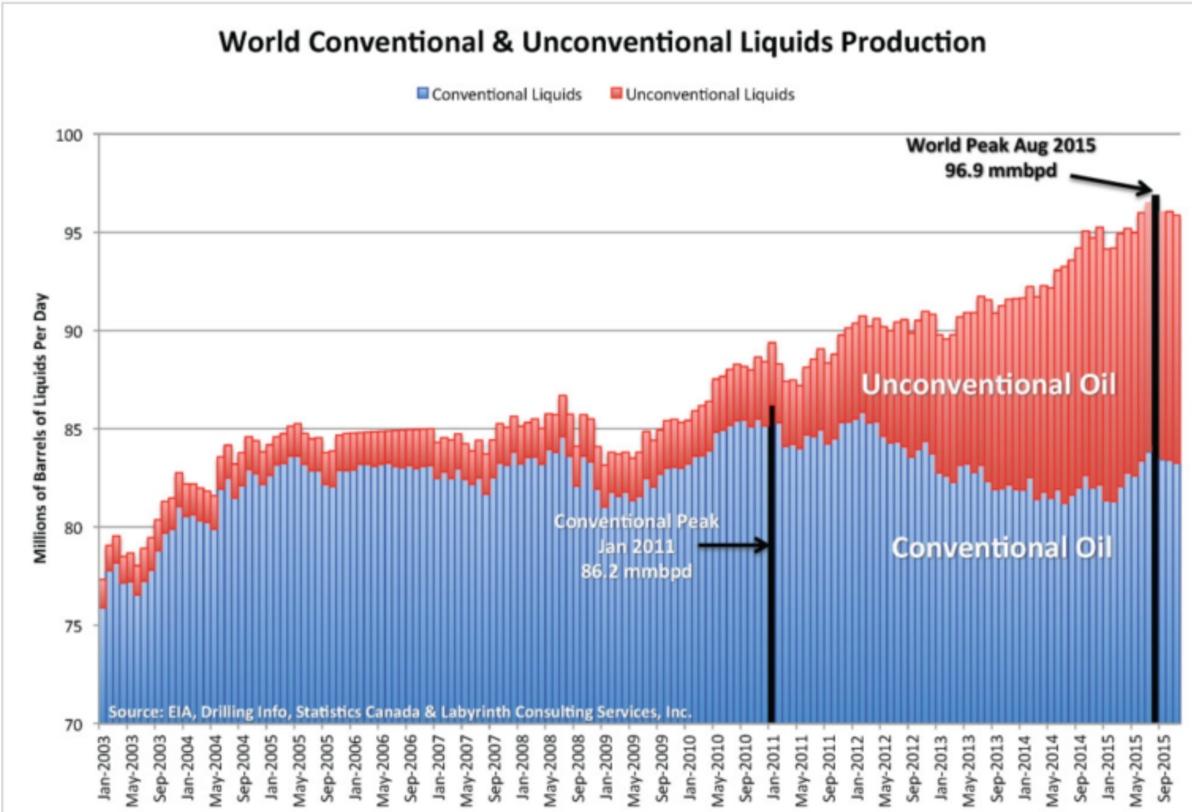

Figure 3.9 Growth in liquid fossil fuels has only been sustained through the rapid development of unconventional sources (Source: Berman, 2015).

shows the growth of unconventional oil to closely match unidentified projects), represents a shortfall of over 60 MMbpd by 2031 which when compared to the average oil export production of 10 MMbpd for Saudi Arabia in 2011[104], represents the equivalent to conventional oil from six Saudi Arabia's that would have to be brought into production within the next twenty years, meaning a new Saudi Arabia discovered and developed every 3 years, 4 months (IEA, 2008).

[104] The export of any nations can be found at Energy Export Databrowser which uses data from BP Statistical Review.

Conventional and Unconventional Natural Gas

Natural gas (mostly methane) is classified as conventional or unconventional depending on whether the gas was easy and straightforward to extract or if it required more specialized techniques such as hydraulic fracturing[105], horizontal or multilateral drilling and chemical scrubbing, but like oil, there exists no formal accepted definition for unconventional natural gas (Chew, 2014). Unconventional natural gas is often found as a free gas with methane bubbles trapped in the pore spaces of deeper reservoirs rocks of sandstone, limestone or chalk (tight gas) or as an absorbed gas that has adhered in shallower reservoirs of the surface of kerogen and clay minerals (shale gas) (Broderick, Wood, Gilbert, Sharmina & Anderson, 2011; Summers, 2011; Chew, 2014). Natural gas is also found in coal seams, absorbed on the surface of coal (termed coal seam gas) and in either of the polar and high altitude permafrost regions or in water depths greater than 300 m with temperatures near 0°C as clathrates (Chew, 2014).

Global natural gas consumption has grown from 1973 when consumption was a little over 1/6 of all energy consumed (78.5 Tcf) to over 1/4 in 2014 (149 Tcf) representing a 190% increase (IEA, 2015d). Under EIA's most recent BAU reference case, global consumption is projected to rise to 203 Tcf by 2040 with industry and electricity accounting for near 3/4 of this growth (EIA, 2016a). However, the meeting of production needs for this projection has been met with concerns by EIA (2016b), previously challenged by Hughes (2014) and later by Berman (2016a) over the concerns that earliest production focused on the best regions, leaving poorer resources to be developed later, presenting a problem of growing expansion in the face of collapsing price.

[105] Hydraulic Fracturing is commonly termed fracking or in industry circles, fracing.

Current world natural gas proved reserves stand at 6,950 Tcf[106] with almost three quarters located in the Middle East and Eurasia (EIA, 2016b).

Shale, tight and coalbed methane gas in EIA (2016a) projections from global sources (see Figure 3.10) are all expected to significantly rise to 2040 in efforts to reduce dependency of coal and work towards reducing pollution and CO_2 emissions. Shale gas and tight oil are co-products from fracking shale deposits where assessable gas is withdrawn quickly requiring new fracking to extend the flow of this gas. This results in gas wells experiencing a rapid decline in production after one year, requiring additional investment to refrack the bore hole and continue the flow of remaining trapped gas (Berman & Pittenger, 2011; Hughes, 2011, 2014; Berman, 2016a). This rapid depletion has reduced extractable shale oil and gas production to a few sweet spots compared to the vast area where this resource exists (Berman & Pittenger, 2011; Inman, 2014; Livingston, 2014). As a fuel source, the decline rate associated with natural gas from conventional and unconventional sources in the U.S. mean, these wells must continuously be drilled to maintain supply[107]. In 2001, prior fracking, the U.S. natural gas decline rate of conventional resources was around 23%, leaving a need to replace 4.4 Tcf/a of resource to maintain a consumption level of 20 Tcf/a. Ten years later, by adding fracked sources, the average decline rate has increased to 32%, meaning an approximate 8.0 Tcf must be replaced on a yearly basis to maintain the same levels of consumption (Berman, 2012). As drilling and recovery of the shale gas plays continue, estimates from the initial amount of recoverable gas continue to

[106] Global estimates of natural gas reserves are considered conservative since they commonly assume a 10% recovery rate (Chew, 2014).
[107] The common metaphor associated with the sustained drilling and fracking is the Red Queen Syndrome: ‘Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!’ (Lewis Carroll, Alice in Wonderland Ch. 2).

decline, from an initial value of 1,744 Tcf to the more recent 389 Tcf due to challenges of poor permeability of what can be economically extracted (Kargbo, Wilhelm & Campbell, 2010; USGS, 2014). Placed in context of the U.S. consumption level of 20 Tcf/a, the shale plays amount to a little under 20 years of higher priced natural gas, directly contradicting an image of U.S. energy independence[108] with many wondering if shale gas is a blessing or curse.

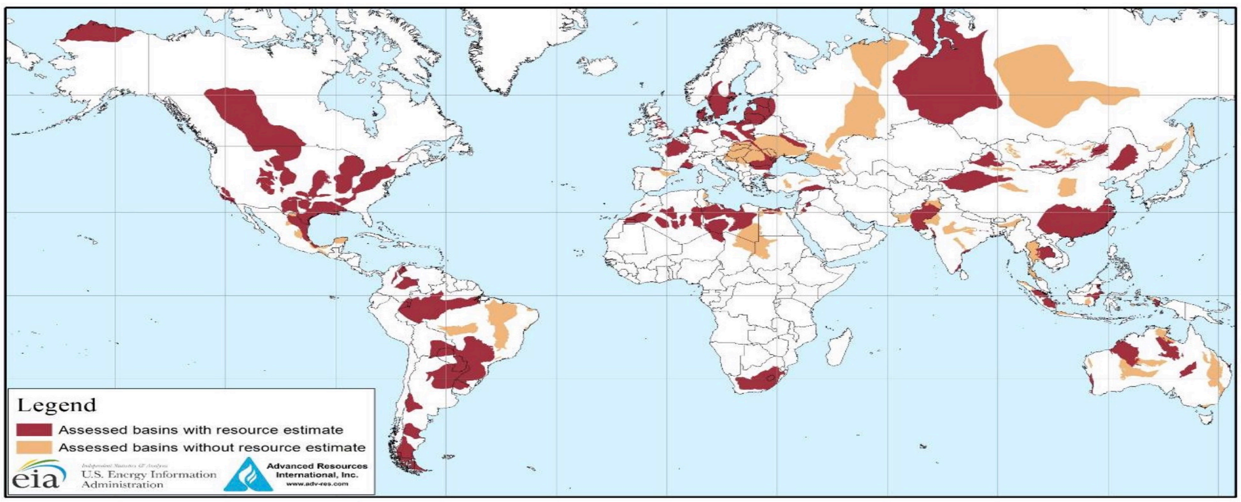

Figure 3.10 Map showing major global shale gas basins. U.S. EIA (2015b) assessed shale gas basins around the world in 46 countries concluding the international resource proven reserves were equivalent to conventional reserves. When combined, EIA estimate assessed shale gas basins have more than 7580 trillion cubic feet of recoverable gas (Source: EIA, 2013, 2015c)

Fracking as a source of unconventional gas and oil production is increasingly contested from multiple concerns including earthquakes, methane escape, wasteful flaring, excessive water use, water contamination, radioactive waste and regional health impacts (Sovacool, 2014a). Underground waste disposal of the brines recovered from fracking and the large amounts of

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[108] Examples of media publications promoting the idea of US Energy Independence can be found at The New York Times-http://www.nytimes.com/2012/03/23/business/energy-environment/inching-toward-energy-independence-in-america.html?_r=1, ABC News-http://www.abc.net.au/news/2012-02-29/kohler-oil-reserves-shift-global-markets/3859118

brines injected have been linked to dramatic increases in earthquakes in fracked regions resulting in the USGS producing maps highlighting regions at risk from induced earthquakes (Ellsworth, 2013; Petersen et al., 2016). In the US, the largest methane plume covers 6500 km^2 over the four corners region in the American southwest and is directly linked to emissions leaking from the extraction, processing and distribution of natural gas (Frankenberg et al., 2016). Horizontal drilling with the injection of high volumes of chemicals, sand and water have been linked to the contamination of overlying groundwater aquifers (Hildenbrand et al., 2015; Hildenbrand et al., 2016). Spilled brines used in fracking contain inorganic chemicals, metals and salts that do not biodegrade and they have been found to build up in soils, contaminating rivers and streams and creating significant problems for those trying to clean up these toxins (Lauer, Harkness & Vengosh, 2016). In Pennsylvania, John Hopkins public health researchers have found significant correlation occurring during the most active part of drilling in fracked wells affecting the health of mothers and causing risks to pregnancy (Casey et al., 2016).

Clathrates, Methane Gas Hydrates

Clathrates and gas hydrates have not been included to date by IEA or EIA as sources of unconventional natural gas and researchers are concerned over its possible links to previous mass extinction events (de Santa Ana et al., 2008; Mascarelli, 2009; Maslin et al., 2010). Estimates of amounts of methane hydrates sequestered in marine sediments in the northern permafrost conservatively compare to twice the amount of global recoverable coal, oil and natural gas reserves and are considered to have great potential as a fossil fuel source in the future (Buffet & Archer, 2004; Boswell, 2007; Makogon, Holditch & Makogon, 2007; Kroenlein et al., 2008; Pearce, 2009).

Coal Reserves

Coal is classified into categories of energy density, carbon and moisture, where the highest carbon, lowest moisture coals having the highest energy content and are generally the most desired. There exists no common classification of coal, so one will come across terms such as brown coal, black coal, thermal coal, steam coal, hard coal, all having various definitions dependent to the region (Höök, 2010). By measuring coal's energy density, coal is categorized into anthracite, bituminous, sub-bituminous, and lignite[109]. However, the lack of a common classification makes it important when estimating coal reserves to pay attention to the region where the coal was extracted.

Like oil and gas, one uses the volume of a coal field to estimate the coal reserve. Once coal is extracted from the region of the field to be mined, an estimate of the energy of the recoverable coal is then calculated. Coal recovery is affected by numbers of variables: economic, accessibility, political, health, water, environmental and other issues. Recovery varies greatly from surface mining and underground. Surface mines generally have a high recovery rate when compared to underground where up to 40% can be left as a support for the rock above. Of these two, current global coal production is 40% surface and 60% underground.

Some of the earliest URR coal projections can be found in the mid 1800s projections from Great Britain, where the geologist Edward Hull, first estimated in 1861 that coal supplies in that nation were extensive enough to last over eleven-hundred years of consumption. This number was

[109] Coal classification by energy density: Anthracite: 30 MJ/kg, Bituminous coal: 18.8–29.3 MJ/kg, Sub-bituminous coal: 8.3–25 MJ/kg, Lignite: 5.5–14.3 MJ/kg. Höök (2010).

doubled in 1871 by a Royal commission, projecting a twenty-two-hundred-year supply, a number that has since been found to be far in excess of the one hundred and fifty-year supply produced (Rutledge, 2011). Such projections, wildly over stating reality, still appear to this day. For instance, the 2007 projections from the UN Intergovernmental Panel on Climate Change (IPCC) over available coal resources came under immediate criticism from numerous energy specialists as multiples of what could be realistically expected to be extracted and consumed (Aleklett, 2007; Kharecha & Hansen, 2008; Nel & Cooper, 2009; Rutledge, 2011; Höök & Tang, 2013).

Coal is the second major energy source for civilization (rapidly moving to the top due to Chinese and Indian growth in consumption), but there is a surprising paucity of published estimates on the URR for coal. There are a few studies which focus on the coal reserves to production (R/P)[110] from which a trend can be observed; early studies considered coal abundant whereas later studies indicate otherwise (Mohr & Evans, 2009). Marion King Hubbert, the geologist who first predicted a peak and decline of U.S. oil production in 1970 (Hubbert, 1956), estimated that between 2100 and 2200 would mark the peak production of coal. Laherrère (2006) projected a date of 2050, Zittel and Schindler (2007) projected a date of 2025, Mohr and Evans (2009) 2029 ± 18 years, a number that more recently has been refined to before 2025 due the expected peak in Chinese production (Mohr, Wang, Ellem, Ward & Giurco, 2015). Patzek and Croft (2010) have argued from the analysis of production from current mines, the world should hit peak energy

[110] R/P or RPR is a ratio of the known reserve of a nonrenewable resource divided by the amount that is extracted each year. It is used to give the future availability of the resource. Further detail can be found from Feygin and Satkin (2004) The Oil Reserves-to-Production Ratio and Its Proper Interpretation from (http://www.springerlink.com/content/g741783054628525/fulltext.pdf)

from coal by 2011 and that a decline of 2% should be expected each year to 2050, with 4% per year thereafter.

Coal producing regions have two sets of URR numbers, one from existing mines, supported by engineering studies and a second that uses proved coal reserves (Patzek & Croft, 2010). These two metrics prove useful to those who wish to promote a myth of 200-400 years of coal supply and mine operators who only promise what can be produced, which leaves one to assume an accurate URR is somewhere between these two (Patzek & Croft, 2010). Hubbert in 1970 assumed that the URR for coal was between 270 CMO and 1030 CMO (2,000 Gt and 7,600 Gt). Laherrère (2006) and Zittel and Schindler (2007) estimated between 148-162 CMO of coal would be able to be produced, which later has been dropped to 89 CMO by Rutledge (2011).

Uranium Reserves

Conventional classifications of uranium reserves[111] are termed Reasonably Assured Resources (RAR) and Inferred Resources (IR). Conventional uranium reserves must be extractable with known mining technologies before they can obtain the RAR designation, and then only if they are known to exist with fair certainty. The IR designation is given if these reserves are believed to exist (Dittmar, 2009). These resources are further classified into three groups based on the assumed production cost at the processing plants[112]: the highest-grade costs less than $40/kg to

[111] 1 kg of natural uranium can generate around 38 MWh at a light water nuclear plant, an amount that can be increased to 60% by reprocessing the fuel after being used the first time (Remme, Blesl & Fahl, 2007).

[112] The World Nuclear Association indicated the cost of uranium used to produce electricity, equaled 0.77 cents per kWh in March 2011, contributing less than 10% to the cost of nuclear sourced electricity (Tverberg, 2011b).

extract[113], the middle between $40-$80/kg with the lowest grading between $80-$130/kg (Zittel, Schindler and Bölkow, 2006). Since this processing cost does not include the costs to mine the uranium, large variances can be found in yearly reporting of uranium reserves (Dittmar, 2009)[114]. Unconventional uranium resources are given a classification of Undiscovered Resources (UR) which is broken into two groupings: Undiscovered Prognosticated Resources (UPR) with an assumed middle grade and Undiscovered Speculative Resources (USR) that are assumed a lowest grade or better[115]. Uranium dissolved in ocean water amounts to more than 300 times the known land reserves, but the estimated recovery costs of $200-1000/kg make it noncommercial (Remme et al., 2007).

When one investigates nuclear power as being industrial civilization's rescuer from an energy descent, replacing all fossil sourced power plants would require an increase from the current 435 power plants operating (as of 2008), to 10,730 power plants. This action which would rapidly burn all RAR uranium resources in a little over 5 years (Dittmar, 2011a, EIA, 2012). In extrapolating uranium resource depletion from use in existing power plants, Dittmar believes that construction and completion of new nuclear power plants should cease by 2015, as the known RAR will not be able to meet future demand as shown in Figure 3.11, even if demand decreases by 1% per year (Dittmar, 2011a). This echoes an earlier call in 2006 to curtail the numbers of future power plants that can be built due to the expected risk of fuel shortage (Zittel, Schindler

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[113] RAR below $40/kg to process will be exhausted in 30 years or less (Zittel, Schindler & Bölkow, 2006).
[114] Uranium mines typically last 10 $\pm$ 2 years before depletion (Dittmar, 2011a)
[115] Dittmar in his 2011 Davos presentation on "The End of Cheap Uranium" used the following descriptors for uranium resources: RAR = safe to assume they exist, IR = not found yet but seriously believe they exist, UPR & USR = would like to believe they might exist (adapted from Dittmar, 2011a).

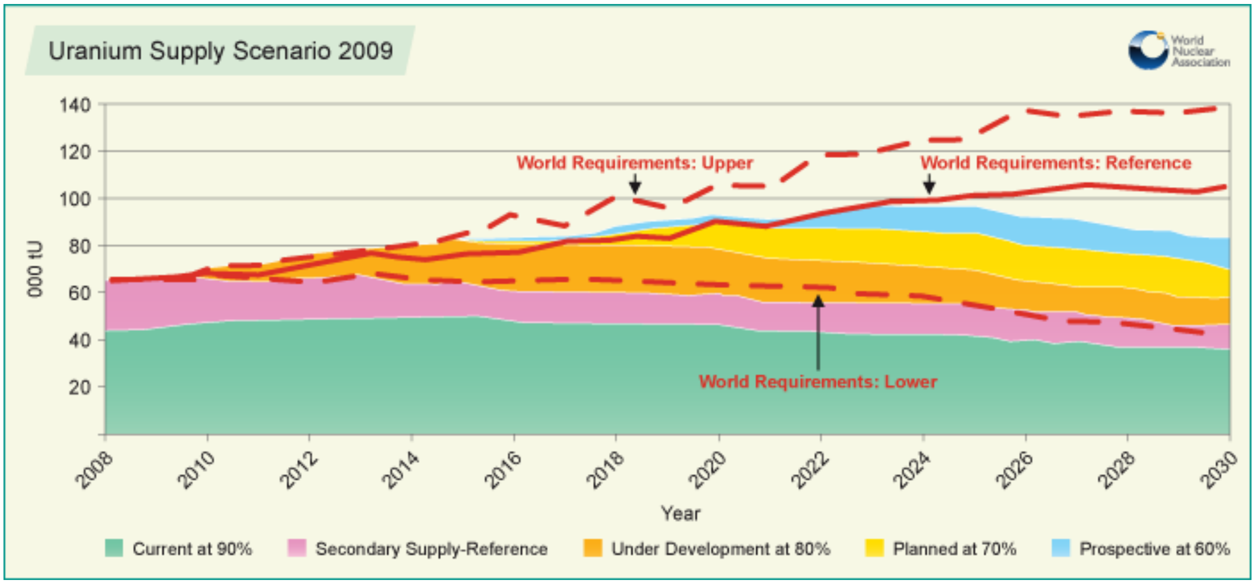

Figure 3.11 Uranium Supply Scenario 2009: reserves and projected shortages for the years 2008 to 2030 (Source: Dittmar, 2011b).

and Bölkow, 2006). Peak conventional fossil energy complicates the future of uranium mining due to diminishing oil needed to run mining and exploration operations and has the potential to wreak havoc in attempting to maintain an adequate supply of uranium to run nuclear power plants (Tverberg, 2011c). Further problems arise from the need of fossil fuel to dismantle and remove radioactive concrete buildings and container vessels after the useful lifespan of the power plant has been reached. Without the means to accomplish this, decommissioned nuclear power plants would be fenced off and abandoned in perpetuity where situated.

The End of Conventional Fossil Fuels

Conventional oil production has plateaued, with evidence of it having plateaued from 2004 to a peak in 2011 then heading into decline (Hirsch et al., 2010; Staniford, 2010; Hallock et al., 2014; Berman, 2015). This exact date of maximum production might be challenged at some point in the future by various factors, but irrespective of the exact date, Shell Oil (2011) has projected that conventional oil production should head into a permanent decline from the current plateau by 2015-2016. This is the fate of all finite fuels: conventional gas is expected to begin its decline around 2020 (Bentley, 2002),[116] and coal production is expected to peak by 2025-2029 (Laherrère, 2006; Kavalov & Peteves, 2007; Zittel & Schindler, 2007) or by one estimate 2011 (Patzek and Croft, 2010). The energy peak production from coal will occur earlier than the extraction peak volume, due to declining energy content of poorer grades of coal entering the market (Heinberg, 2009a; Patzek and Croft, 2010). Uranium as a source of fuel is expected to peak in 2015 (Dittmar, 2011a) and should meet with supply problems by 2020, where after it is expected that "severe uranium supply shortages" will stall any extension of nuclear power (Zittel, Schindler & Bölkow, 2006). When one reviews various literature on fossil energy resource depletion, the year 2025 stands out as around the year where production of all major supplies of conventional fossil fuel will have peaked and entered terminal decline.

[116] This date has been altered by the introduction of natural gas from the fracking of the Barnet shales.

Chapter Four

Fossil Energy Consumption: The Cost of Externalities[117]

Perhaps the greatest challenge acting to slow continued growth in fossil fuel consumption comes from the externalized cost of fossil fuel combustion and the manifestation of this cost through increasingly disruptive global climate change. The effects rising from carbon emissions are now impacting all parts of the planet and one can imagine this as taking on the imagery of global terraforming. When combining this cost with the increased cost to produce lower grades of fossil fuel, one must have an awareness of the risks both hidden and direct in continuing to depend on fossil fuels.

Globalization is founded on the transport of goods and services around the world, and its lifeblood is liquid fossil fuels which represents 95% of all transportation fuel. Global current consumption of liquid fossil fuels has reached 96.9 million barrels[118] which represent a volume equivalent of over two hours, twenty-one minutes the average amount of water that flows over the Niagara Falls. Of concern is the combustion byproduct, carbon dioxide which is an amount that can be approximated by taking the mass of the liquid fossil fuel and multiplying it by 2.70, which means industrial civilizations are currently pumping the equivalent mass of six hours, twenty minutes of the volume of Niagara Falls water released as CO_2 into the atmosphere each

[117] A positive and negative externality can be broadly defined as an activity (or market transition) of one that affects others who have had no part in that activity (or market transaction). ... Pollution is a classic example of this.
[118] Total liquid fossil fuel (lff) production which includes Natural Gas Liquids (NGL), Canadian Tar Sands, North American Shale Oil, Biofuel, Refinery Gains and C + C-tar and shale reached 96.9 million barrels per day in August 2015. The non-conventional share of the liquid fossil fuels at this peak exceeded 12 MMbpd (Berman, 2015).

day. This is only part of industrial civilization's fossil fuel carbon footprint, since liquid fossil fuels only represented 36% of the global fossil emissions in 2013. With coal (43%) and natural gas (21%) in the mix, human caused carbon dioxide emissions have an equivalent of mass of seventeen hours, thirty-six minutes of Niagara Falls water falling each day[119], and is a number that is accelerating (IEA, 2016a)[120].

This recent and rapid rise of atmospheric CO_2 has been documented by Charles David Keeling as shown in Figure 4.1 who starting in the late 1950's began monitoring the CO_2 atmospheric concentrations at the Mauna Loa Observatory, Hawaii. While working on measuring carbon in water, his research required he also do airborne measurements which led him to uncover a regular seasonal cycle for CO_2 reflecting the growth and decay of plants in the Northern Hemisphere. These measurements allowed Keeling to identify that roughly 57% of all fossil fuel CO_2 emissions remained in the atmosphere where the growth of the CO_2 curve was found to correlate to the growth in fossil consumption (Scripps, 2013).

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[119] This is an underestimation of current anthropogenic CO_2 emissions as this only includes fossil fuel emissions and not significant carbon emissions from cement, one tonne of CO_2 per one tonne of cement produced, (Chen, Parsley & Yang, 2010; Vargas & Halog, 2015) and land use (Tubiello et al., 2015).

[120] Climate Central operates an interactive educational site that covers topics such as changes in Carbon Dioxide, Arctic Sea Ice, Ocean Acidification, Extreme Heat, Sea Level Rise and more. Further detail can be found at: http://wxshift.com/climate-change/climate-indicators/carbon-dioxide

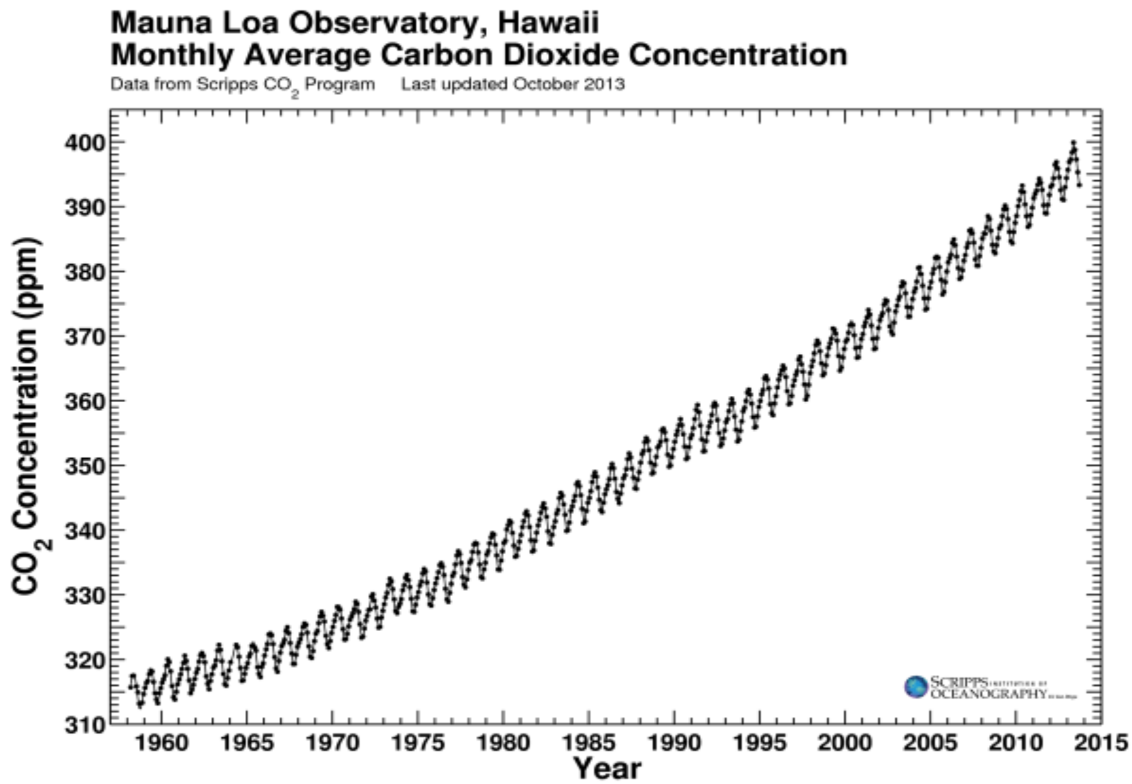

Figure 4.1 The Keeling Curve (Source Scripps (2013).

Anthropocene

The term Anthropocene finds its origin in the 1980's as concept first used by Crutzen and Stoermer[121], later gaining the name "Anthropocene" from Andrew Revkin (1992) who penned "Perhaps earth scientists of the future will name this new post-Holocene[122] period for its causative element-for us. We are entering an age that might someday be referred to as, say, the

[121] The concept of the "Anthropozoic era" can be found in 1864 works quoting Stoppani (Steffen, Grinevald, Crutzen & McNeill, 2011).

[122] The name Holocene (recent whole) was first proposed by Sir Charles Lyell in 1833, formally adopted in 1885 by the International Congress in Bologna (Crutzen & Stoermer, 2010). It is the only one in the past 542 m.y. having a defined start: 10,000 years before 1950 or 10,000 B.P. (Zalasiewicz & Williams (2008).

Anthrocene" (Revkin, 1992, pp. 55), (Crutzen & Stoermer, 2010; Steffen et al., 2011). Crutzen and Stoermer (2000) in IGBP Newsletter 41, suggested that the Anthropocene be identified as the age starting in the late 18th century when global GHG started growing and biotic changes in large lakes began to show (coinciding with the invention of the James Watt steam engine in 1784).

Crutzen and Stoermer's (2000) choice of the late 18th century as the start of the Anthropocene has been expanded to include several identifiable earth surface divisions caused by human activities. The earliest division is proposed to be around 13,800 B.P.[123] and correlates with the extinction of large mammals, which resulted in vegetation and albedo changes in multiple regions. The introduction of agriculture from 8000-5000 B.P. is notable since it caused a detectable change in the atmosphere (Lyons et al., 2015). Two thousand B.P. is identified due to various human civilizations altering the earth's surface. The last two divisions are in the late 18th century with the advent of GHG and the 1950's with artificial radionuclides from hundreds of atomic bomb detonations. Crutzen and Stoermer's (2000) choice of GHG emissions remains the metric that has gained the most attention in its formalization of fossil fuel consumption and climate change into Anthropogenic Global Warming (AGW). Of these 5 geologic divisions, it is with the advent of GHG emissions that will act to take humanity from the relative stability of the Holocene (see Figure 4.2) to one of global climate disruption where traditional climate patterns can no longer be assumed to be reliable. Clive Hamilton, (2016) in critiquing the numerous rationale and different onsets of anthropocentric impacts, states the multiplicity of these different

[123] B.P. or bp is a notation representing "Before Present" and is standardized as before the year 1950.

anthropocentric ages work to divorce themselves from fossil fueled industrialization, making the anthropocene seem as some benign event in human history, and he states the anthropocene is not some friendly future and scientists have a responsibility to give evidence why it is alarming.

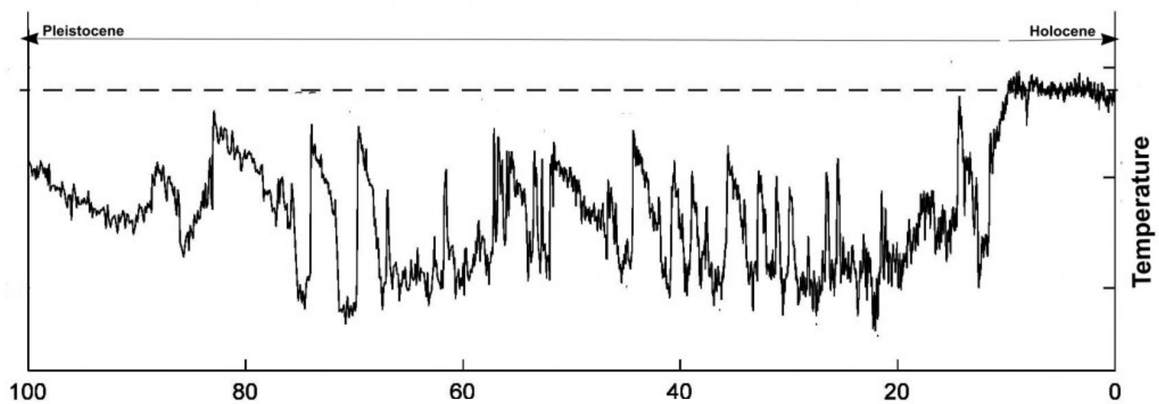

Figure 4.2 Paleoclimatic temperature reconstruction from 100,000 years b.p. to present showing the 20°C instability of the Pleistocene as compared to the relative stability of the Holocene (Source: Angus, 2015: Adapted from Potsdam Institute for Climate Impact Research)

In 1998 Michael Mann[124] (Penn. State University), lead author in a paleontological statistical reconstruction of hemispherical data, constructed a graph of temperature anomalies (see Figure 4.3) from 1000 AD (Mann, Bradley & Hughes, 1998). The graph of this temperature anomaly[125] was figure 3 on the last page of the published paper "Northern Hemisphere Temperatures During the Past Millennium Inferences Uncertainties and Limitations". This paper, which has over 1800

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[124] Michael Mann talking describing this experience at Virginia Polytechnic Institute and State University Link: https://vtechworks.lib.vt.edu/handle/10919/51650

[125] Temperature anomalies are measured relative to a baseline located at pre-industrial levels. While most researchers take this baseline to be the average global temperature between 1850 to 1900, Hawkins, E., P. Ortega, E. Suckling, A. Schurer, G. Hegerl, P. Jones, …, and G. van Oldenborgh (2017) argue that this baseline should reflect the temperatures that occurred between 1720 and 1800, since this would indicate any increase in temperature could then be linked to human activity and not natural variation.

current citations, ignited a firestorm of climate science obstructionist attacks including death threats directed at Mann who was then a post-doc at University of Massachusetts, Amherst

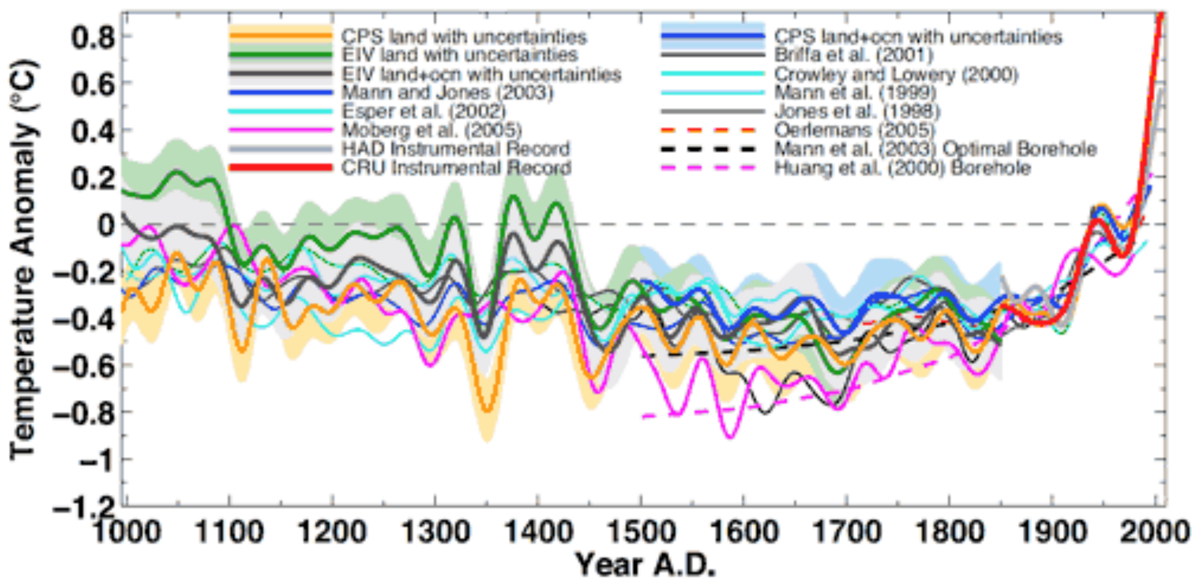

Figure 4.3 Northern Hemisphere temperature reconstruction from 1000 A.D. confirming the earlier hockey stick shaped projection of Mann et al., (1998). Source Mann et al., 2008.

(Mann, 2012, 2015).

The physics and chemistry at the foundation of Mann's work has been known for over two centuries. Fourier in 1824[126] and 1827[127] published two papers that are considered the foundation that first proposed the idea of a greenhouse effect [128] recognizing the role of the earth's

[126] Fourier J (1824). "Remarques Générales Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires". *Annales de Chimie et de Physique* **27**: 136–67.
[127] Fourier J (1827). "Mémoire Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires". *Mémoires de l'Académie Royale des Sciences* **7**: 569–604.
[128] John Tyndall (1861) was the first recorded scientist to use the words "Greenhouse Effects" in "On the Absorption and Radiation of Heat by Gases and Vapours, and on the Physical Connexion of Radiation, Absorption, and Conduction" *Philosophical Magazine ser. 4*, 22: 169-94, 273-85.

atmosphere in keeping the planet warmer than was expected due to the incoming solar radiation. All work since then has been refining the science of climate change (Mann. 2015).

The role of CO_2 is significant, since the earth without any GHG would be 254K (-19°C) rather than its current average temperature of 288K (15°C), planets Venus 184K (-89°C)[129] instead of 737K (464°C) and Mars 210K (-63°C) instead of 218K (-55°C) (NASA, 2015). Calculating the temperature of a non GHG planet owes its mathematical form to Max Planck in 1900 who refined Kirchhoff's law of thermal radiation from works in 1869 and 1862. The equation that can be used to calculate the temperature of the Earth is shown below and is universal for any planet, requiring only a small amount of needed measurements: temperature of sun, distance away from the sun, radius of planet and its albedo.

$$\mathbf{Temp_{earth} = Temp_{sun}\ (1\text{-}reflectivity_{earth})^{1/4}\ [(radius_{earth})/(2x\ distance\ to\ sun]^{1/2}}$$

$$\mathbf{or\ ...\ T_E = T_S\ (1\text{-}\partial)^{1/4}\ [R_E\ /\ 2D_S]^{1/2}}$$

[129] It is common to see different black body temperature calculations for all planets that can be found on the internet. Outside of math errors, these differences are in the reflectivity constant (albedo, ∂) used in the calculation.

GHG[130] measurements from 800,000 years B.P.[131] show a higher CO_2 atmospheric concentrations (see Figure 4.4) than anything experienced on earth in the past 800,000 years (Lüthi et al., 2008; Stocker et al, 2014). Global paleo-temperature reconstructions from the National Climatic Data Center range of a low of 179 ppm to a high of near 300 ppm and show a range of nearly -9°C to peaks of 3°C from the past 150,000 years, which is alarming since the 2013 CO_2 concentration was 30% above this (NOAA)[132]. BAU CO_2 atmospheric emissions that have accelerated since the advent of the industrial revolution now place the earth's atmosphere at a level last seen at the start of the Pleistocene, 2.6 million years ago, and if continued even at a slightly reduced pace for

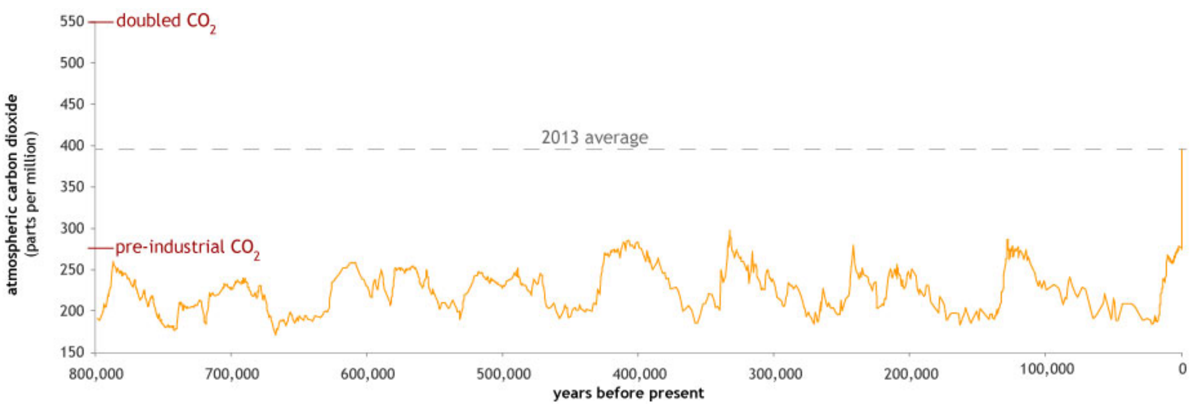

Figure 4.4 Atmospheric CO_2 emissions from 800,000 b.p. to present, based on EPICA Dome C data from Luthi et al., (2008) (Source: Lindsey, 2014).

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130 The effect of CO_2 is due to its ability to reflect infrared heat energy back to the earth. For CO_2 concentrations, close to what existed in the past 800,000 years, the doubling from 140 to 280 ppm represented a warming of 4 W/m^2 and for the next doubling concentrations would need to jump from 280 to 560 ppm (4 W/m^2 equals 1.2°C warming). Warming by CO_2 is amplified by 6.5 times from fast and slow feedbacks from water vapor, clouds, ice and other earth systems, data supported by paleoclimatic measures such as the bottom of the ice age with an average global temperature of -5°C at 180 ppm and 15°C warmer at 1000 ppm in the Eocene epoch (Wasdell, 2014).

131 More information on the 800,000-year Ice-Core Records of Atmospheric Carbon Dioxide (CO_2) can be found at the Carbon Dioxide Information Analysis Center (CDIAC) research center at the Oak Ridge National Laboratory. Link: http://cdiac.ornl.gov/trends/co2/ice_core_co2.html

132 More information about the NOAA paleoclimatology center can be found at this link: http://www.ncdc.noaa.gov/data-access/paleoclimatology-data/about-the-paleoclimatology-program

the rest of the century, will turn the anthropocene to conditions last seen in the Eocene epoch of the Cenozoic, 50 million years in the past (Weitzman, 2015; Crucifix, 2016).

Current work in projected climate impacts of carbon dioxide are produced using Atmosphere-Ocean General Circulation Models (AOGCMs) and Earth System Models of Intermediate Complexity (EMICs)[133]. IPCC in its latest Fifth Assessment Report (AR5) (IPCC, 2013b)[134, 135] has "very high confidence" in the model's abilities to "reproduce observed large-scale mean surface temperature patterns (pattern correlation of ~0.99)" (IPCC, 2013b, pp. 743). Furthermore, AR5 models now "allow for policy-relevant calculations such as the carbon dioxide (CO_2) emissions compatible with a specified climate stabilization target" (IPCC, 2013b, pp. 743).

Researchers at the Potsdam Institute of Climate Impact Research (PIK) using the earth's atmosphere, ocean, ice sheets in a model exploring the relationship between Atmospheric CO_2 and the Milankovitch cycles[136] analyzing earth orbit and incident solar intensity, have matched the onset conditions of the last eight glacial cycles (see Figure 4.5) occurring during the Pleistocene (Crucifix, 2016; Ganopolski, Winkelmann & Schellnhuber, 2016). PIK's model

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[133] IPCC AR4 and AR5 used AOGCM models with considerable confidence due to their ability to reproduce both past climate change features along with current observations. For questions that involve long time spans EMIC models are used in the AR4 and AR5 reports (IPCC, 2007; IPCC, 2014).

[134] Previous IPCC Assessment Reports are noted as: First (FAR), Second (SAR), Third (TAR), Fourth (AR4).

[135] Links to all IPCC Special Reports: https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#4

[136] Milankovitch cycles (≈ 100,000 years for a complete cycle) relate to variations in the Earth's orbital eccentricity, axial tilt and precession which when combined alter the amount of solar radiation reaching the Earth's surface.

indicates that at the start of the industrial age, conditions had been near perfect for the onset of a new glacial cycle which when once passed was not expected to occur again until approximately 50,000 years into the future. Anthropocentric CO_2 emissions have now pushed the date of the next glacial cycle to at minimum 100,000 years into the future (Ganopolski et al., 2016; Schellnhuber, 2016).

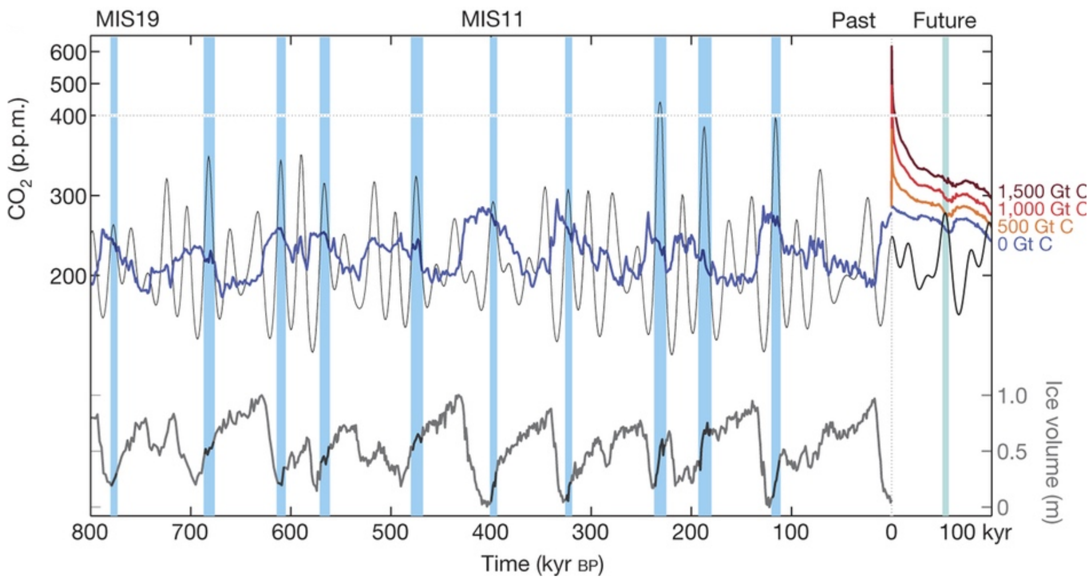

Figure 4.5 Measured CO_2 (dark navy line) and the Milankovitch cycle (light gray) showing the onset of glacial cycles corresponding to the intersection of CO_2 concentrations and solar intensity (Source: Ganopolski et al., 2016).

IPCC's AR5 Climate Change: Synthesis Report provide several stark warnings and statements, first with their notes on uncertainty to convey in clear terms what they mean with each finding they present. Readers will see statements such as "Human influence on the climate system is clear" (IPCC, 2014, pp. 2)[137], "Warming of the climate system is unequivocal" (IPCC, 2014, pp.

[137] Andregg et al., (2010) in analysis of 1372 climate researchers found there to be a 97-98% agreement with the IPCC primary conclusion that anthropogenic greenhouse gases have been responsible for most of the observed average AGW. Benestad et al., (2015) in analyzing the publications of the 2% of the researchers rejecting AGW discovered that multiple flaws from

2) and “Anthropogenic greenhouse gas emissions have increased since the pre-industrial era driven largely by economic and population growth[138] ... to levels that are unprecedented in at least the last 800,000 years” (IPCC, 2014, pp. 4).

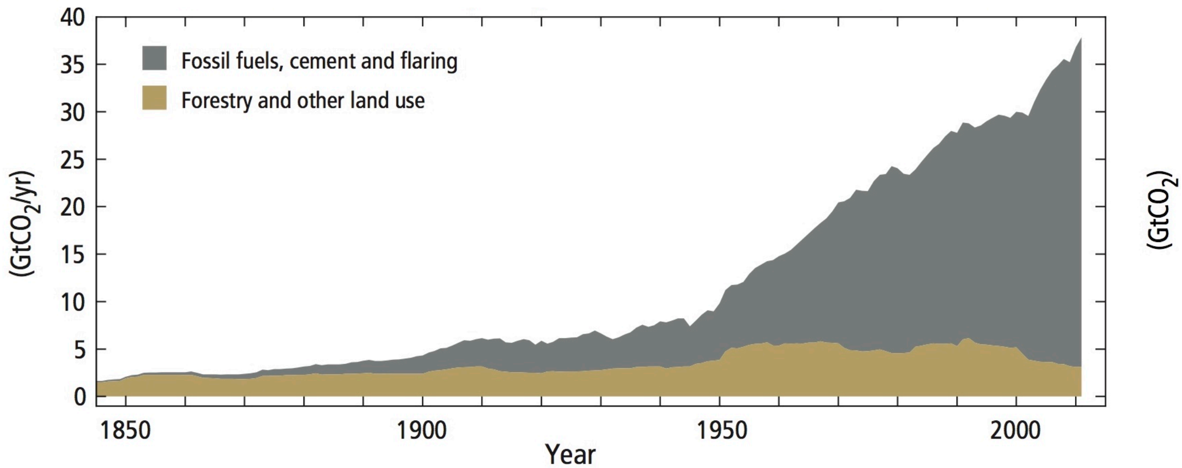

Figure 4.6 Global anthropogenic CO_2 emissions from 1850 to present, identifying the prominence of fossil fuel consumption and cement compared to other land use, primarily agriculture (Source: IPCC, 2013b).

IPCC (2013a) AR5 assessment of CO_2 emissions found fossil fuel combustion and industrial processes amounted to 78% of the total greenhouse gas emissions in the forty-year span between 1970 and 2010 (see Figure 4.6). Specifically, these emissions have contributed to warming effects over all parts of the planet including the oceans surrounding Antarctica and have been linked to Arctic sea ice loss since 1979[139], the retreat of glaciers since 1960, increased melting of

insufficient model evaluation, false dichotomies, incomplete or misconceived physics and inappropriate statistical methods.

[138] British Petroleum (BP) (2016) project growth in carbon emissions to be a function of increases in population and income, where nearly all the expected growth in future emissions will come from developing countries, with the demand from developed countries remaining unchanged.

[139] The Arctic traditionally is defined as being ice-free when it has shrunk to less than one million square km.

Greenland since 1993[140], affecting the global water cycle since 1960, have substantially increased the upper 700m of ocean heat and is responsible for more than half of all surface temperature increases from 1951 to 2010 (IPCC, 2013a; Armour, Marshall, Scott, J. Donohoe, & Newsom, 2016). El Niño and La Niña[141] related to extreme climate events such as tropical cyclones, hurricanes, drought, fires, floods and ecosystem and agriculture disruptions are expected to double, bringing profound socio-economic consequences (Cai et al., 2014; Cai et al., 2015). Ceballos et al., (2015) state that crops yields are increasingly showing climate influenced negative impacts that now outweigh the positive for all countries except a few and irrespective of development, and signs indicate there is a significant lack of preparedness for the expected climate variability impacting some sectors from which there is an expected long term increase in economic loss.[142]

> Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. Increasing magnitudes of warming increase the likelihood of severe, pervasive and irreversible impacts for people, species and ecosystems. Continued high emissions would lead to mostly negative impacts for biodiversity, ecosystem services and economic development and amplify risks for livelihoods and for food and human security (IPCC, 2014, pp. 64).

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[140] The National Snow & Ice Data Center (NSIDC) located at University of Colorado Boulder, provides regular scientific updates on Antarctica, Greenland and the Arctic Sea Ice. Further detail can be found at: http://nsidc.org.

[141] El Niño are eastward directed and La Niña are equator directed events.

[142] From 1994 to 2013 over 530,000 people died as a direct result of extreme weather, suffering an estimated $2.17 trillion USD in damages (Kreft, Eckstein, Junghans, Kerestan & Hagen, 2014).

IPCC Future Scenarios

Only one AR5 IPCC future has an expected global temperature increase to remain below 2°C[143]. This future requires the stringent mitigation scenario classified as Representative Concentration Pathway 2.6[144] or RCP 2.6 that reaches a radiative forcing peak of 3.1 W/m^2 by 2050, declining to 2.6 W/m^2 by 2100[145]. IPCC RCPs standardize GHG[146] emissions enable various climate models to be compared to and validated by other researchers using different models. For AR5, IPCC explored four representative emission scenarios RCP2.6, RCP4.5, RCP6.0 AND RCP8.5[147, 148] (van Vuuren et al., 2011). Each RCP scenario consists of a large data base of numbers containing emissions estimations to 2100 drawn from energy sources, economic growth, population projections and socio-economic expectations for different regions (Girod, Wiek, Mieg, & Hulme, 2009; van Vuuren et al., 2011). These scenarios, based on published

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[143] Current IPCC models correlate an increase of 1 trillion tonnes atmospheric CO_2 to an expected peak surface temperature ranging between 0.8 °C and 2.5°C (IPCC, 2014).

[144] Graham Wayne (2013) created a guide enabling readers to understand the various IPCC RCP scenarios that were used in AR5 replacing the Special Report on Emissions Scenarios (SRES) used in the previous TAR and AR4 Synopsis Reports. Further detail can be found at: https://skepticalscience.com/rcp-guide-part1-post.html

[145] Radiative forcing of 3.1 W/m^2 assumes an equivalent CO_2 atmospheric concentration of 490 ppm and 2.6 W/m^2 at 400 ppm (IPCC, 2013b).

[146] Total greenhouse gas emissions (CO_2 e) are standardized to a common base of CO_2 warming by multiplying the amount of each type of emission by its Global Warming Potential (GWP).

[147] RCP8.5 has passed through several name changes in the IPCC reports, first as A1C in assuming continued growth in coal usage, then as A1F1 to broaden the GHG sources to all fossil fuels and currently as RCP8.5 which relates to the expected GHG radiative forcing in W/m^2 (Bunzi, 2014).

[148] The scenario RCP8.5 is challenged as not plausible, since current fossil fuel URR estimates are not extensive enough to release the needed CO_2 emissions (Mohr et al., 2015; Clark et al., 2016). From studies exploring both conventional and unconventional fossil energy sources, the highest projection expects fossil production and consumption to grow until 2025, then plateau for half a century before entering decline (Mohr et al., 2015).

literature from existing peer reviewed research[149] are downloadable to all researchers[150] with the purpose to initialize and standardize all climate models run (Wayne, 2013).

Of these four scenarios, RCP2.6 is the only scenario where a decline in oil consumption occurs, where consumption reduces due to oil depletion, rising fossil energy prices and stringent climate policies. This scenario is lower than any of the previous SRES scenarios used in the TAR and AR4 assessments by introducing carbon changes into the "supply mix' such as bio-energy. Negative emissions[151] (latter half of the 21st century) are expected to play a significant role through Carbon Capture Systems (CCS)[152] and are expected to allow for some partial resumption of fossil energy consumption later in the century after which emissions are projected to remain constant after 2100. Anderson and Peters (2016) identify a risk of carbon capture storage or planned negative emission technologies being used in these RCP scenarios results from the possible failure to implement or if they are unsuccessful, leaving humanity to be locked into a higher temperature path. In all IPCC RCP scenarios, non-fossil energy consumption is expected to increase (van Vuuren et al., 2011; Fuss et al., 2014).

[149] The synthesis of RCP2.6 came from over 20 similar scenarios from different studies (van Vuuren et al., 2011).
[150] RCP Database (version 2.0) Link: http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome
[151] "Negative emissions cannot be used to continue Business as Usual and then remove the bulk of the emissions mid-century. The required carbon flows would simply be too large, while such a strategy possibly also suffers from the negative environmental feedbacks associated with Business as Usual in 2050" Fuss, S. & Czernichowski-Lauriol, I (2015, July 9).
[152] John Riley (so-director of Science and Policy of Global Change, MIT) criticizes Carbon Capture Systems in models as "BAU Party on Schemes" with an optional payment plan in the future (Tollefson, 2015).

IPCC AR5 Projected Temperature Increase

Worrisome projections coming out of the AR5 synthesis are comparisons between the RCP2.6 (< 2°C) and the RCP8.5 (BAU) scenarios, where the latter is expected to reach 2.6°C to 4.8°C average temperatures by the end of the century (see Figure 4.7). Clarke, Jarosch, Anslow, Radić & Menounos, (2015) in a study of western Canada found that glaciers will shrink 70% ± 10% by 2100 relative to their size in 2005 and that few glaciers will remain in the interior and Rockies regions. This melt will see the peak of glacial sourced water between 2020 to 2040 and that for all scenarios outside of RCP2.6, the area and volume loss from glaciers in the interior and Rockies will exceed 90%. This implies expected widespread ecological damage to any system dependent on the constant supply of the cooler glacial fed waters such as pacific salmon streams and habitats. Also, the lack of retention of water in ice and snow packs projects extensive flooding during heavier fall and winter rains. Researchers at the Max Planck Institute in Germany in 2014 discovered from their models that the expected Arctic warming (IPCC AR5 scenarios) is too conservative. This comes from their finding that a cold layer cap of air over the

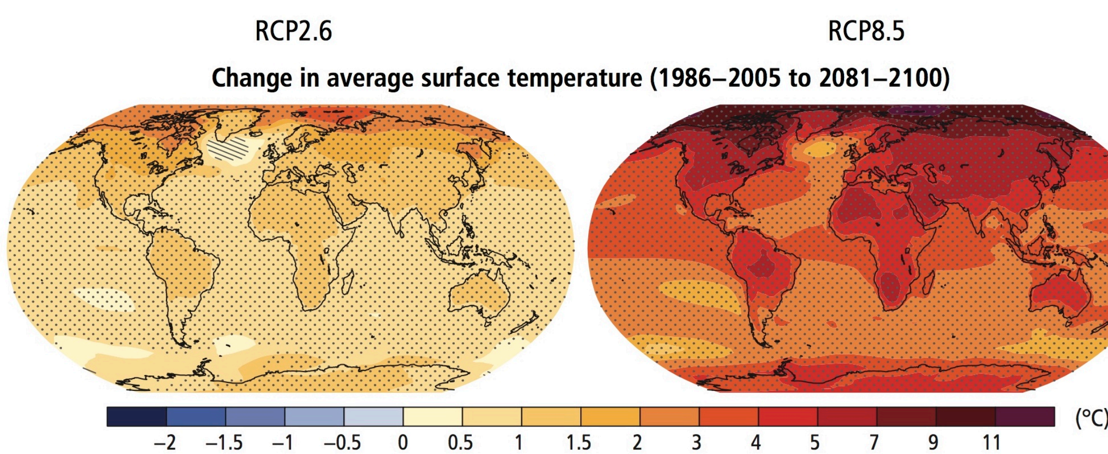

Figure 4.7 IPCC AR5 Synthesis Report image showing the projected average surface temperature increase between the RCP2.6 and RCP8.5 (BAU) models over 95 years (Source: IPCC, 2013a).

Arctic will act to retain more heat than is gained from the expected heating increase due to albedo increase (Pithan and Mauritsen, 2014; Stephens, O'Brien, Webster, Pilewski, Kato & Li, 2015). Warming is also expected to have a devastating effect on Southwest Asia (or the Middle East) which is expected to become increasingly uninhabitable under the BAU scenario as human adaptability necessitates a wet bulb[153] temperature under 35°C[154] (Pal and Eltahir, 2015).

> A world in which warming reaches 4°C above preindustrial levels (hereafter referred to as a 4°C world), would be one of unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on human systems, ecosystems, and associated services (World Bank, 2012, pp. 13).

IPCC AR5 Projected Precipitation Change

BAU projected precipitation change (see Figure 4.8) can be characterized as a massive disruption to current rainfall patterns from the climate movement from mid-latitudes towards the poles due to a phenomenon termed Hadley Cell expansion[155] (Dyer, 2009; Norris et al., 2016). In Central America, Caribbean, Western Balkans, Middle East and North Africa regions that will be subjected to increasing temperature, rainfall is projected to decline as much as 20-50% (Stocker et al., 2014). Guiot and Cramer (2016) in an paleoanalysis of pollen recovered from sediment have concluded that the Mediterranean vegetation expected to survive rainfall and temperatures projected under 1.5° C warming would most likely become a region of desertification at 2°C or

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[153] Thermometers measure dry bulb temperature (T_{db}). Thermometers having the bulb moistened, will measure the cooling effect of the moisture evaporating (T_{wb}). This wet bulb temperature represents the cooling effect of shaded sweating skin in strong breeze. $T_{wb} > 35°C$ is too hot for a 37°C human to successfully radiate excess heat.

[154] Six hours of continuous exposure to 35°C wet bulb temperature is considered lethal (Sherwood & Huber, 2010).

[155] Hadley Cell expansion is where the air circulation in the regions ± 30° on either side of the equator is expected to increase as the difference in temperatures between the poles decreases. This will increase the desertification of all land within this region.

above temperatures. Other regions of Central and Eastern Siberia and northwest South America can expect increased rainfall intensities of 30% or greater. The BAU world of the future is one of increased desertification and flooding (Stocker et al., 2014; World Bank, 2014; Guiot & Cramer, 2016; Norris et al., 2016).

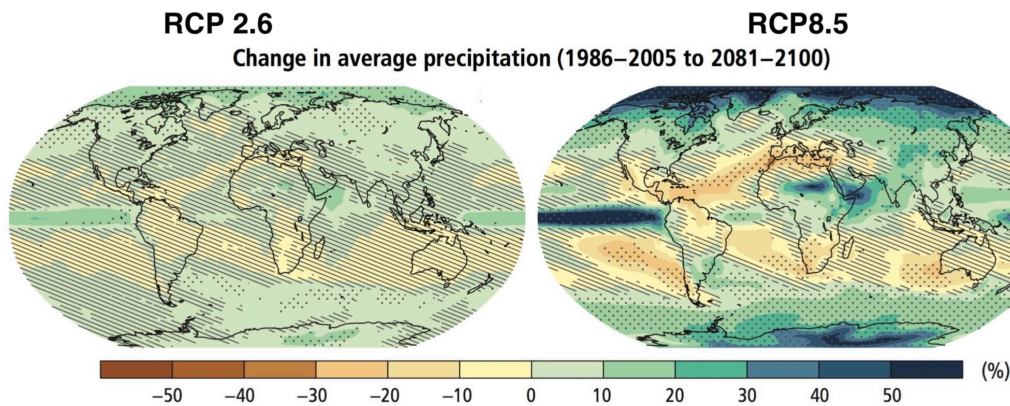

Figure 4.8 IPCC AR5 Synthesis Report image showing the projected average precipitation change between the RCP2.6 and RCP8.5 (BAU) models over 95 years (Source: IPCC, 2013a)

Food security will suffer as expected yields are expected to encounter rapidly increasing and significant impacts after the average global temperature climbs 1.5-2°C. In this range, even at the RCP 2.6 scenario, there is an expected 30-70% decline in soybeans and 50% for wheat in Brazil, Central America and the Caribbean while Macedonian losses for wheat, maize, vegetables and grapes are expected to drop to half of previous yields. In projecting, modeled losses from temperature increases, losses from the expected increase in droughts and flooding remain uncertain (World Bank, 2014).

Another impact is increasing numbers of projected refugees, i.e. the Syrian refugee crisis, that resulted in floods of refugees from the ongoing civil war attempting to remove the Assad government, having roots to the 2007-2010 drought in the greater Fertile Crescent (Kelley, Mohtadi, Cane, Seager & Kushnir, 2015)[156]. This region with "unsustainable agricultural and environmental policies" experienced a drought that modeled current anthropogenic long term warming trends for this region. This resulted in up to 1.5 million rural farming families moving to urban areas, following the 1.2 to 1.5 million Iraqi refugees a few years earlier, leading to the chaotic conditions of overcrowding, crime and unemployment and to the uprising against the Assad government (De Châtel, 2014; Kelley et al., 2015). Gemenne (2011) expects the numbers of climate refugees[157] [158] in 2050 to range from 50-200 million, IPCC (2013a) projects these numbers to increase to hundreds of millions by 2100 under the RCP8.5 or BAU scenario. Hsiang and Sobel (2016) in looking at just a 2°C increase in temperatures, have concluded that tropical human populations and ecosystems would be required to migrate distances greater than 1000 km to survive, where in some regions, populations densities could increase 300% or more. The numbers of migrants from their study are staggering, with roughly 1/8 of global population traveling 1000 km and 1/3 migrating in excess of 500 km. Surviving ecosystems in Hsiang and Sobel's (2016) scenario would have to make similar migrations in less than 90 years, meaning an ecosystem migration speed would be in the range of 11-22 km/yr. While many will be moving to escape water, food and health issues from rising temperatures and altered precipitation patterns,

[156] Solomon Hsiang described Kelley's work as "the first scientific paper to make the case that human-caused climate change is already altering the risk of large-scale social unrest and violence" (Krajick, 2015).

[157] United Nations High Commissioner for Refugees (UNHCR) recorded more than 51 million refugees worldwide in 2014. Further detail can be found at: http://www.unhcr.org/pages/49c3646cbc.html

[158] While both climate refugee and environmental refugee are commonly used terms, most experts consider them inappropriate since they obscure critical complexity (Adger et al., 2014).

there are also large coastal populations that will also be displaced due to rising sea levels (see Figure 4.9).

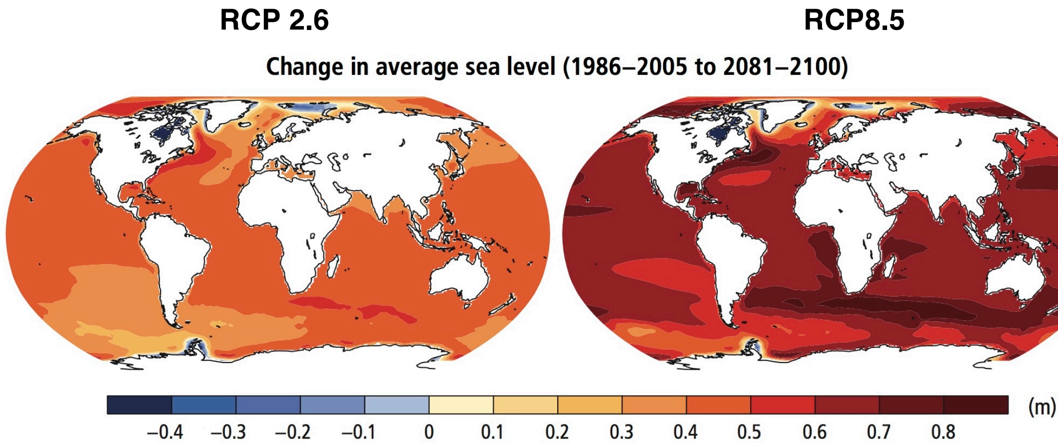

Figure 4.9 IPCC AR5 Synthesis Report image showing the projected average sea level increase between the RCP2.6 and RCP8.5 (BAU) models over 95 years (Source: IPCC, 2013a)

IPCC AR5 Projected Sea Level Increase[159]

Albert et al., (2016) in using time series satellite and aerial photographs of low-lying vegetative islands in the Solomon's, have discovered five of thirty-three islands being studied have vanished during the years from 1947-2014 and another six-experienced severe shoreline recession in regions of the highest wave energy, documenting evidence of the expected fate of similar elevated islands. Tuvalu, the 189th member of the United Nation and the poster child of "climate refugees" is expected to be the first nation to become uninhabited as the storms and tides from a rising sea level flood and salt the soil, destroying the ability of the island to grow food (Farbotko and Lazrus, 2012). Identifying a time of expected island abandonment is

[159] Geoscience News and Information maintains an interactive site that allows one to explore any region on the planet to see the effects of a 0-60 m rise in sea level. Further detail can be found at: http://geology.com/sea-level-rise/

hindered by a variety of temporally linked processes such as decadal and multi-decadal variations that affect the acceleration of sea level rise (Haigh et al., 2014), but Haigh expects that before 2030 there should exist "some statistically certainty" of sea level rise for the end of this century to allow for several generations to plan for and adapt to the expected global sea level rise[160].

While Tuvalu represents the loss of a 3000-year-old island civilization, there are significant numbers of small island states that have been recognized by the UN, UNFCCC and IPCC as being among the most vulnerable of countries facing sea level rise and projected extreme weather events (Hoad, 2015). In addition, over 150 million humans live on areas that are only one metre above high tide[161] and 250 million live within five metres, meaning hundreds of millions will be affected in any scenario of increased storm frequency driving salt water intrusion into fresh water sources and onto food producing lands (Lichter, Vafeidis, Nicholls & Kaiser, 2011). UNEP (2014) summarized the potential and expected impact of rising sea levels to include flood and storm damage, loss of wetlands, erosion, rising water tables along with salt water intrusions where all have socio-economic and environmental cost.

Current contributions to sea level rise are linked to thermal expansion of sea water (about 30% from 1993 to 2009), the increased amount of melting of ice on Greenland and Antarctica (about 60% from 1993 to 2009) with the remaining sourced from the evaporation and glacier melting

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[160] Margaret Davidson (NOAA) and Michael Angelina (ARMI) presenting at the RIMS16 Conference (San Diego, April 2016) using yet to be published data, announced that sea levels could rise by 3 metres by 2050-2060 (Jergler, 2016).

[161] Levermann et al., (2013) project a rise of sea-level corresponding to 2.3 m/°C within the next two millennia from current GHG emissions in the atmosphere.

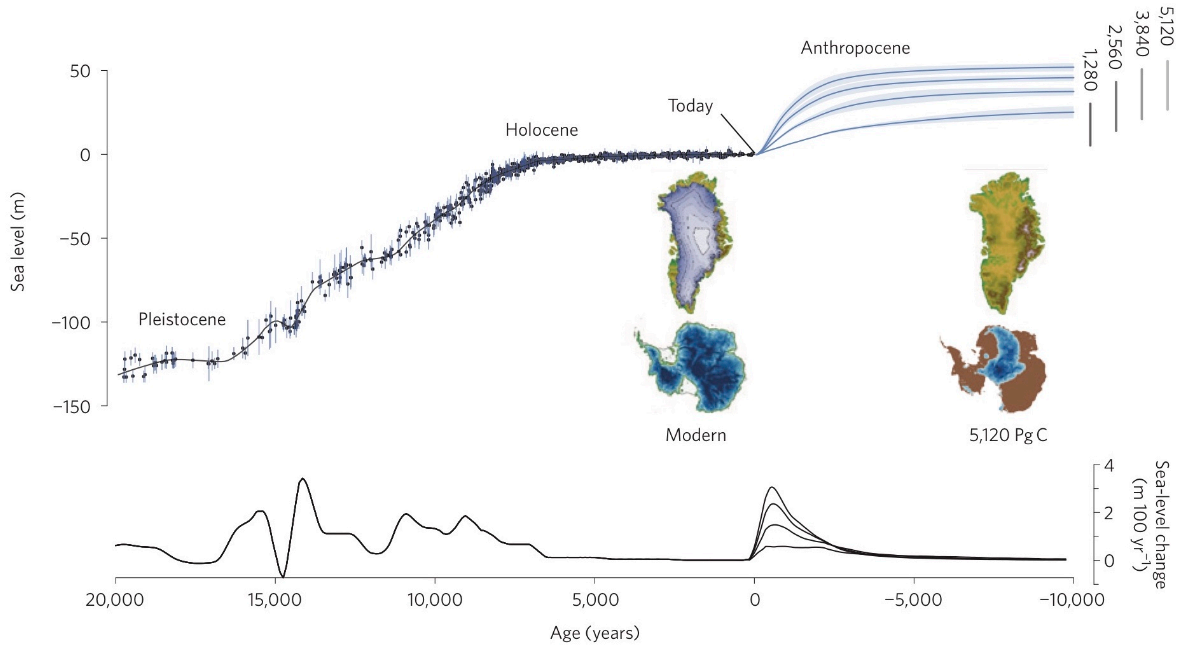

Figure 4.10 Measured sea level rise from 20,000 b.p. (uncertainty indicated by vertical blue lies) projected to 10,000 years into the future showing RCP4.5 as the lower emission line for 1,289 GT CO_2 and RCP8.5 as the upper emission line for 5120 $GtCO_2$ (Source: Clark et al., 2016).

from all other regions (Nicholls & Cazenave, 2010). Paleoceanographic studies (see Figure 4.10) show that sea level, having been consistent for 4000 years, has only since the late 1800's began to rise, at 1.7 cm/decade and rising to 3.2 to 3.3 cm/decade since the 1990's, although the latest IPCC AR5 synthesis expects rates to be higher than 3.2 to 3.6 cm/decade (Nicholls & Cazenave, 2010; Meyssignac & Cazenave, 2012; IPCC, 2014). The various IPCC AR5 scenarios project a range of sea level rise to be between 0.26 to 0.55 m for RCP2.6 and from 0.52 to 0.98 m for RCP8.5 by 2100.[162] For scenarios running to 2300, RCP2.6 projects a maximum rise to less than 1 m and between 1 to 3 m for RCP8.5. Evidence has been gathered that there is a threshold temperature between 2°C and 4°C that would lead to the near-complete melt of the Greenland Ice Sheet over a millennium, raising global sea level by 7 m (IPCC, 2014).

[162] In more recent studies, Jevrejava, Grinsted and Moor (2014) put the odds at lower than 5%, that sea levels will rise above 1.80 m for the RCP8.5 Scenario.

Paleoclimatic Concerns about the 2°C Limit

Recent paleoclimatic science developments have emerged from the investigation of the Eemian period approximately 130,000 to 115,000 years ago where the sea level rose 5 to 9 m at an estimated rate of 1 metre per century[163] above todays average sea level, during atmospheric CO_2 levels of 270 ppm which are 135 ppm lower than present (Luthi et al., 2008; Hansen et al., 2016). These Eemian paleoclimate studies are of interest because at most, Eemian temperatures were within 2°C of current pre-industrial temperatures[164] and within the current limits set for RCP2.6. What Hansen et al., (2016) have uncovered is that sea ice melt above a certain amount can shut down ocean circulation, specifically the Southern Ocean Meridional Overturning Circulation (SMOC) and the Atlantic Ocean Meridional Overturning Circulation (AMOC) which could be expected to result in catastrophic anthropogenic climate forcing rates by as much as 50 W/m^2, a near thirtyfold increase over the current rate of 1.7 W/m^2. Paleoclimatic evidence of the violence of Eemian Caribbean storms occurring during this interglacial period have been found in deposited debris 20 to 40 m above sea level and kilometres inland. These storms were also found to be responsible for having buried and preserved trees 8-10 m tall, several metres above sea level (Hearty & Olson, 2011).

Shao and Ditlevesen (2016) in their study of temperature, ice core and sediment measurements over the past five million years uncovered evidence pointing to relatively stable climate systems during the interglacial periods such as the current Holocene. Interpreting this evidence using

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[163] Complicating this research is that Deschamps et al., (2012) has found Eemian paleoclimatic evidence that indicated a 5 m rise in sea level occurred in a single century.
[164] Masson-Delmotte et al., (2013) concluded that peak Eemian temperatures were within a few tenths of a degree warmer than present.

fractal analysis indicates the prospect of increased climate extreme weather conditions will be humanity's future as global climate systems shift further away from the Holocene. Should the violence of Eemian storms reappear in the next couple of centuries, one can expect extensive destruction of large inhabited areas near sea level and loss of all coastal cities[165] (Hansen et al., 2016).

Concerns over IPCC Synthesis & Summary Reports

IPCC[166] is one of science's most conservative climate science organization and because of this, statements have continued to underestimate the severity of expected climate change (Brysse, Oreskes, O'Reilly & Oppenheimer, 2013; Wigley and Santer, 2013; Dyer and Davis, 2015; Howard & Sylvan, 2015; Mann, 2015). Part of this is due to the process of using peer reviewed evidence in the synthesis reports. The process of submission a peer reviewed paper to its acceptance and publication for science, technology and medical (STM) fields typically take nine months[167] (Björk and Solomon, 2013) and this does not include the time needed for the research to be completed in the first place. Cut off dates are created for papers to be used by IPCC, which are then analyzed and summarized, taking sometimes taking two years before the final synthesis is published (Spratt, 2007; Dyer, 2009). Simply, IPCC synthesis reports are out of date when published.

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[165] Hansen et al., (2016) have found evidence sea level rise could accelerate to a metre or more per decade.

[166] Note IPCC does no science or research, rather it functions to collate research from multiple disciplines researching climate science and create synthesis reports of their findings. IPCC uses peer reviewed research for their reports but will use "grey material" in areas where there is a lack of peer reviewed work to supplement peer reviewed. The use of such grey material has led to attacks on the scientific validity of IPCC.

[167] Björk and Solomon (2013) found that it took an average of eighteen months for papers in social science, arts, humanities, business and economics to clear the peer review to publish date.

Conservatism in IPCC summary reports for policy makers (SPM) stems from its process in using a two-step process, with the SPM written first by IPCC authors and then reviewed and approved "line by line" by government representatives. It is the process of getting governments to approve that has caused controversy, recently by the actions of Saudi Arabia backed by China[168] in blocking and altering information that worked to define a global carbon budget discussed in the IPCC AR5 report (Wasdell, 2014). Wasdell's personal condemnation of government interference in IPCC is as follows;

> On these grounds the Summary for Policymakers of the IPCC AR5 WG1 should be rejected as not fit for policy-making. It is a compromise between what is scientifically necessary and what is deemed to be politically and economically feasible. It is a document of appeasement, in active collusion with the global addiction to fossil sources of energy (Wasdell, 2014, pp. 21).

Another issue concerning IPCC reports is from the way climate science has been communicated to the public. IPCC use a combination of assumptions, models and observations to create their future projections and include a probabilistic range of happening. Watson et al., (2016) point out that confusion resulting from deliberate misinformation from non-scientific sources working to maintain BAU has led many to perceive IPCC reporting on climate change as undecided, abstract and distant. Watson et al., (2016) further point out that public support and understanding is foundational to immediate actions that are needed to address the growing challenge created from continued fossil energy consumption and other human behaviors that are leading to growing GHG emissions.

[168] Wasdell's (2014) critical evaluation of the IPCC AR5 SPM can be found at this link: http://www.apollo-gaia.org/AR5SPM.html

The Global Carbon Budget and the 2°C Target[169, 170, 171]

Two degrees; above it and the planet might descend into a Mordor where below 2°C there remains a chance to stabilize and have time to adapt, but this limit is complicated by communities heavily contesting both sides of 2°C (Tschakert, 2015)[172, 173]. Currently, the industrial civilization continues to burn and release carbon at the highest IPCC RCP8.5 scenario[174] expected to lead to an eventual temperature between 3 to 4°C[175] or higher instead of the desired 1.5 to 2.0°C (Peters et al., 2013; European Commission, Joint Research Centre

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[169] The origin of the 2°C limit can be found in a William Nordhaus 1975 paper "Can we control carbon dioxide?". In this paper, Nordhaus notes: "In particular, it appears that emissions of carbon particulate matter, and waste heat may, at some time in the future, lead to significant climatic modifications. Of these, it appears that carbon dioxide will probably be the first emission to affect climate on a global scale, with a significant temperature increase by the end of the century" (pp. 1). Summarizing this data, his conclusion was that if global temperatures rose to 2-3°C above the current temperature, then humanity would be living in a climate with temperatures above and outside the range observed from the last "several hundred thousand years." Further detail can be found at: https://www.carbonbrief.org/two-degrees-the-history-of-climate-changes-speed-limit

[170] In their report to AVOID, the BAU approach that would not work to reduce emissions means that by 2100, a global temperature increase of 5.2°C can be expected with impacts including yearly flooding affecting 120 million (29 million) people, increased water stress impacting 2 billion (1.5 billion) humans, 12 billion (1.3 billion) yearly incidences of human exposure to heatwaves each year and that the feasible crop growing area would decline by 7.7 million km^2 (4.5 million km^2). Adhering to a 2°C limit would reduce these numbers to the second set of numbers contained in the brackets following the first (Arnell et al., 2015).

[171] Anderson & Peters (2016) point out that it is impossible to correctly assign a carbon budget to a specific temperature increase due to complexities involved.

[172] Small island states argue that 2°C privileges the interests of the northern countries since globally 1.5°C or 2°C presents different manifestations around the world (Nelson, 2015; Tschakert, 2015).

[173] Lewis (2016) has identified a paucity of research focusing on a target of 1.5°C with most "impact and scenario studies" centered on 2°C. Lewis further states this is a legacy of funding focused on developed nations, bias that he declares dangerous and in this framing, works to entrench global inequality.

[174] RCP8.5's primary energy mix is dominated by conventional and unconventional fossil fuels as a result of both increasing population and demand for food (Riahi et al., 2011).

[175] 4°C under the BAU Scenario could be reached as early as 2070 (World Bank, 2014).

(JRC), 2015, October 27). Agreements to limit global warming to 2°C[176] have been in place since 2010 by both United Nations Framework Convention on Climate Change (UNFCCC) and Conference of the Parties (COP)[177] and has resulted in working to initiate adaptation policies (Jordan et al., 2013). The initial part of reduction to decreasing GHG is in creating short to medium term targets (2020-2050) for mitigation of GHG emissions that are achievable through fossil energy demand destruction from efficiency improvements, carbon tax and other initiatives from 2015-2025 (Anderson, 2012). It is in the timeframe of 2025 to 2050 that fossil energy supply constraints must then be added to curb emissions to the desired rate of zero. One of the challenges to meeting these carbon reduction emission pathways is in political interpretations of projected economic severity in enacting carbon reduction which has led to dangerous government policies in failing to act quickly (Anderson & Bows, 2011). Anderson and Bows (2011) in criticizing government policy state:

> Put bluntly, while the rhetoric of policy is to reduce emissions in line with avoiding dangerous climate change, most policy advice is to accept a high probability of extremely dangerous climate change rather than propose radical and immediate emission reductions (pp. 40).

Meinshausen et al., (2009) using a Monte Carlo Simulation quantified the need to restrain carbon emissions to within a carbon budget remaining for the industrial civilization and humanity to

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[176] The EU adopted the 2°C target in 1996, followed by the G8 (1998), COP16 (2010) and UNFCCC in Cancún (2010) (Haigh, 2016).

[177] COP21 resulted in the surprise agreement (with strong objections from Saudi Arabia and India) to work to limit global warming to 1.5°C, dictating a zero carbon world needs to be achieved by 2030, using as it's reference the UN report FCCC/SB/2015/INF.1 that can be accessed at http://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600008454

burn[178], should it wish to live on a planet restrained to 2°C warming. The quantities given for acceptable remaining CO_2 emissions were: 1000 Gt to leave a probability of a 75% chance to remain below 2°C or 1440 Gt if one accepted the riskier 50% odds[179] (Meinshausen et al., 2009). This led them to state "... less than half the proven economically recoverable oil, gas and coal reserves can still be emitted up to 2050 to achieve such a goal (pp. 1158)." These emission restraints were updated in the IPCC AR5 (2014) synthesis to allow for a 90% chance of remaining below 2°C and reduced cumulative total emissions to 2440 Gt, CO_2 (from 1870 to present) of which 2000 Gt have been already emitted by 2013, leaving a 440 Gt[180] carbon budget for future generations.[181, 182, 183]

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[178] Global GHG emissions can be freely accessed using the World Resources Institute-Climate Analysis Indicator Tools (CAIT 2.0) Further detail can be found at: http://cait.wri.org/historical/Country%20GHG%20Emissions?indicator%5b%5d=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator%5b%5d=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year%5b%5d=2012&sortIdx=NaN&chartType=geo

[179] McKibben (2012) metaphorically relates the odds of 50% remaining below 2°C to having a six shooter loaded with 3 bullets and then playing Russian Roulette with it.

[180] If one is to look at this 440 Gt budget to see how long humanity can continue its BAU path, it becomes a relatively easy exercise. Converting 440 Gt to fossil fuel energy requires the removal of 10% for non-fossil fuel sources leaving 396 Gt of fossil fuel CO_2 emissions. This 396 Gt (if all oil) represents around 1250 Gbl of oil. Yearly global oil consumption IEA(2015a) is estimated to be currently more than 34 bbl of oil, representing roughly 1/3 of all fossil fuel consumption which means that humanity is currently burning through around 113 billion Barrels of Oil equivalent (boe) each year. This leaves the BAU scenario with 1250/113 or about 11 years at current consumption. One must be careful with simple calculations like this, because every type and grade of fossil fuel has different CO_2 emissions, and since coal consumption is the heaviest CO_2 emitter of the three main fossil fuels and is the most commonly used fuel, this approximately 11 years of BAU becomes shortened. Note: Giga-barrels (Gbl) is the same measure as billion barrels (Bbl).

[181] 1000 Gt CO_2 were emitted during each period from 1870-1980 and 1980-2013.

[182] Increasing the odds of remaining below 2°C removed approximately 500 Gt of allowable CO_2 emissions coming mainly from fossil fuel consumption (Jackson, Friedlingstein, Canadell & Andrew, 2015).

[183] Total fossil fuel reserves from Coal, Oil and Gas were in excess of 2500 Gt of CO_2 emissions at the time Meinshausen et al., (2009) published their paper.

The Emissions Gap

Starting in 2010 UNEP started publishing what is referred to as "The Emissions Gap Report", a report that investigates the gap between needed GHG emission reductions consistent with the 2°C carbon budget limit and of ongoing emissions. In its simplest form, quantification of atmospheric growth of CO_2 (G_{atm})[184] is found by taking the sum of Fossil Fuel and Cement CO_2 emissions (E_{ff}) and Land Use Change CO_2 emissions (E_{luc}) and subtracting the CO_2 absorption or uptake (termed carbon sinks) by the Ocean[185] (S_{ocean}) and land sinks (S_{land}) (Le Quéré, Peters, Andres, Andrew, Boden, Ciais, ..., & Yue, 2013). In equation, this is as follows[186]:

$$\mathbf{G_{atm} = [E_{ff} + E_{luc}]\text{-}[S_{ocean} + S_{land}]}$$

The global carbon budget[187, 188] is revised on a yearly basis to account for changes reflecting the changes in the various emitters and sinks of CO_2 and improvements in data measurement and collecting (Le Quéré et al., 2013). In the 2014 annual "Emissions Gap Report" negative

[184] G_{atm} is often reported in ppm and is found by converting 2.210 GtC as equaling 1 ppm (Joos et al., 2013).

[185] Long et al., (2016) have found that some parts of the ocean are already showing negative externalities in the reduction of oxygenated water due to continued CO_2 absorption. By 2030-2040 an inability to mix oxygen with the lower layers through either phytoplankton or exchange with the atmosphere these "oxygen minimum zones" will be widespread and easily detectable with plants, organisms and fish that live in these lower layers negatively affected. This nutrient delivery gap is considered the principle cause of the inability of the marine species to recover from the 96% Permian-Triassic extinction event where geologic records indicate that it took an estimated nine million years for ocean temperatures to cool before zooplankton recovered (Grasby, Beauchamp & Knies, 2016).

[186] All units in this equation are in Gt carbon (GtC), where 1 GtC equals 3.664 Gt CO_2.

[187] Revised global carbon budget updates are found at: http://www.globalcarbonproject.org/carbonbudget/index.htm

[188] One needs to be careful in looking at carbon budgets, since carbon costs are not the same as CO_2 emission costs. 3.67 tonnes of CO_2 emissions are equivalent to one tonne of carbon (OECD, 2016).

emissions were included to allow for an expected budget overshoot, where carbon neutrality would then be reached somewhere between 2050 and 2070, with global GHG emissions to reach net zero between 2080 and 2100. To date GHG emissions have been found to be tracking the BAU scenario where atmospheric carbon dioxide in 1992 at 356.4 ppm[189] rose sharply to 398.6 ppm in 2014 an increase of nearly 12%[190]. The correlation between BAU GHG projections is one that Jarvis and Hewitt (2014) expect to continue due to evidence they have gathered indicating "significant inertia" in evolving global energy systems coupled with the "absence of novel interventions".

Conference of Parties (COP)

In Rio de Janeiro 1992, The Earth Summit[191] convened to reduce and stabilize GHG emissions with the objective to "prevent dangerous anthropogenic interference with the climate system" (UNFCCC[192], 1992). To date, there have been 21 annual COP meetings to assess all progress in limiting GHG emissions. The original treaty set no limits on emissions, contained no enforcement mechanisms, making it a legally non-binding treaty, working to identify a framework that would allow the creation of future international "protocols" that could then set binding limits on GHG emissions. The first of these treaties came in 1997 at COP 3, creating the Kyoto Protocol[193] which established the first legally binding treaty for developed countries. In

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[189] CO_2Now.org publish Atmospheric CO_2 from Mauna Loa Observatory (MLO) and can be assessed at http://co2now.org/current-co2/co2-now/annual-co2.html

[190] The CO_2 concentration 1997 (Kyoto Protocol) was 363.7 ppm indicates a 9.6% increase to 2014.

[191] The Earth Summit 1992 is often referred as the first Conference of Parties (COP) instead of COP 1 Berlin 1995.

[192] United Nations Framework Convention on Climate Change, also referred to as FCCC. Link to the UNFCCC site: http://unfccc.int/2860.php

[193] Kyoto Protocol link: http://unfccc.int/kyoto_protocol/items/2830.php

2010 at Cancún COP 16, a target of limiting GHG emissions to remain below 2°C was set in what became known as the Cancún agreements[194].

COP 21

COP 21 had the stated objective of reaching a legally binding and universal agreement on GHG mitigation and was hopeful in gathering international efforts using a budget approach, to restrain emissions to remain below 2°C. These international efforts constraining GHG emissions come from various governments pledges termed Intended Nationally Determined Contributions (INDCs)[195]. When tabulated the difference (gap) between what is needed to stabilize at 2°C and the projected BAU scenario show that intended pledges (see Figure 4.11) are currently enough to reduce expected warming to 3.6°C by 2100 and represent 36% of needed changes[196]. While COP21[197] INDC pledges had been criticized as only buying five to ten years to act, these pledges mirror the incremental approach[198] to reducing harmful emissions that were destroying the ozone, a global effort that has since began to witness ozone growth and repair (Solomon et al., 2016). The most common of the INDC policies and actions used in restraining GHG emissions are the

[194] Link to the Cancún agreements: http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=4
[195] A list of governments and their INDC pledges can be found at: http://climateobserver.org/open-and-shut/indc/
[196]The Donella Meadows Institute (MIT), host site of the Climate Interactive maintains a scorecard of the INDC pledges and the reductions they are expected to bring. https://www.climateinteractive.org/tools/scoreboard/
[197] Saudi Arabia made international news over accusations in their attempts to sabotage COP21. http://www.theguardian.com/environment/2015/dec/08/saudi-arabia-accused-of-trying-to-wreck-the-paris-climate-deal
[198] A brief history of the Vienna Convention (1981) and Montreal Protocol (1987) leading to the agreements to protect the ozone can be found at International Institute for Sustainable Development (IISD). http://www.iisd.ca/process/ozone_regime_intro.htm

"market-based instruments"[199] (MBI's) of "Cap and Trade" and "Carbon Tax" which were promoted due to presumed lower economic cost (Lockie, 2013).

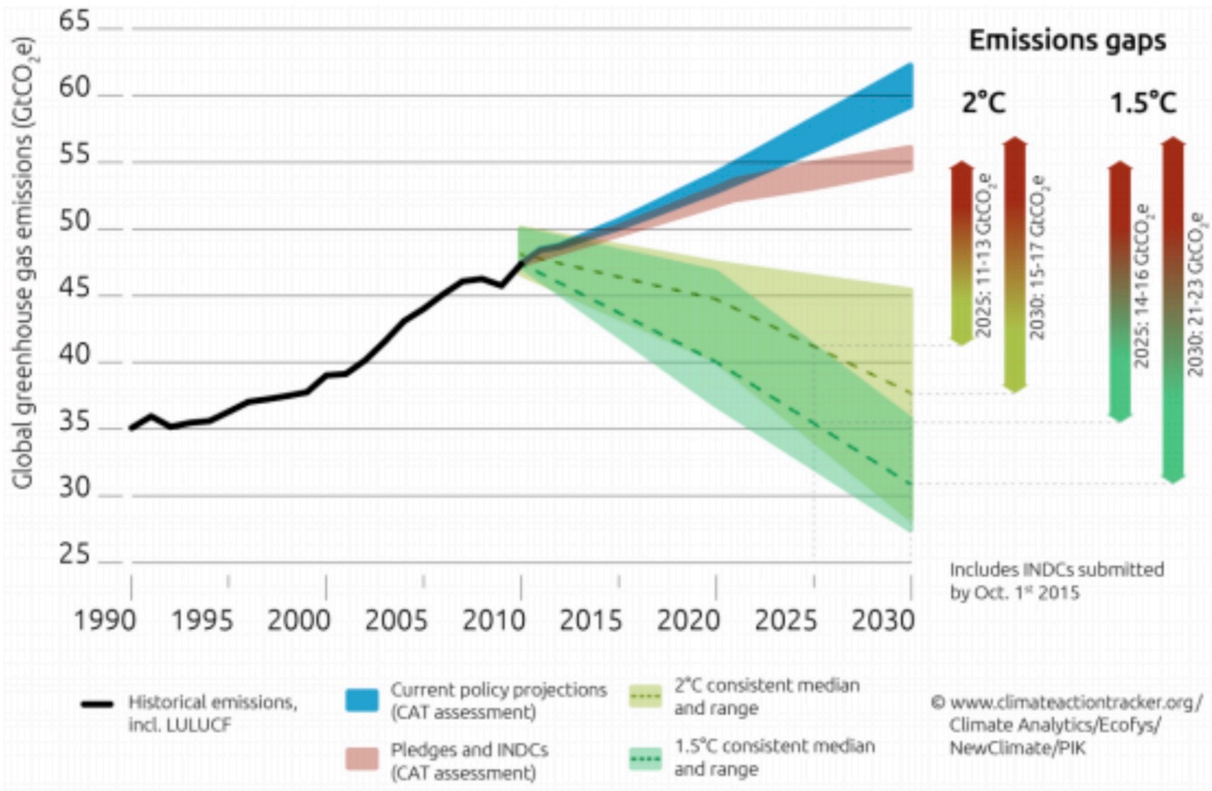

Figure 4.11 INDC Emissions gap between policies, pledges and pathways that lead to a target of 1.5°C and 2°C (Source: Climatetracker.org, 2015)

199 Cap and Trade and Carbon Taxes is criticized by ecological economist as the solution of "monetize nature and let free markets do their magic", more commonly described as "internalizing the externalities" (Rees, 2015).

1.5°C to Stay Alive[200, 201]

Joanna Haigh FRS in a guest blog for The Royal Society (February 8, 2016)[202] summarized the mood of COP21 as debating "if any possible agreement at all could be reached and if a 2°C limit would have any chance at all reaching any final text". COP21 attendees in identifying a 2°C limit as harmful to the small island nation ("one point five to stay alive" was their COP21 slogan) surprised all in making a target of 1.5°C one of serious consideration (Nelson, 2016; Haigh, 2016; Lewis, 2016). While this did not result in agreed limit, the 1.5°C became "formalized as a future aspiration" (Haigh, 2016).

In the IPCC AR5 (2014) Synthesis report, scientists made it explicitly clear that the probability of the transition point to high from a moderate risk occurred somewhere between 1.1-1.6°C warming and that at 2°C, the risk was high. Schleussner et al., (2015) describes the difference in impacts from a 1.5°C to a 2°C[203] as substantial where considering heat, the related extremes in a 1.5°C world is at the "upper limit of present-day natural variability" and that a new climate

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[200] The 1.5°C target has been a key demand of the Alliance of Small Island States (AOSIS) since 2008. Tuvalu in leading AOSIS and African Nations brought COP15 the following year to a complete stop in their demands for a 1.5°C target, a position that was aggressively opposed by China and India. While the 2°C target was agreed to in COP15, the following year COP16 agreed to review the 2°C target (Tschakert, 2015).

[201] Midway through COP21, Saudi Arabia and India blocked referencing the UNFCCC (2015) Report on the structured expert dialogue on the 2013–2015 review, with leaders from Delhi and Riyadh saying the report's findings were a direct threat to their economies (Climate Change News reporting from COP21). Link to the blocked UN report: http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf

[202] https://blogs.royalsociety.org/in-verba/2016/02/08/two-months-on-from-the-paris-agreement-thoughts-from-a-climate-scientist/?utm_source=Adestra&utm_medium=email&utm_campaign=4369

[203] More than 175 nations gathered on April 22, 2016 to sign the COP21 agreement to limit global warming between 1.5°C and 2°C which has since climbed to 195 nations (Nature, 2016; Watson et al., 2016).

regime could be expected at 2°C. In comparing the impacts between 1.5°C and 2°C, projects that at 2°C nearly all tropical coral reefs are at risk[204], water availability in the Mediterranean decreases from 9 to 17%, expected dry spells are expected to increase in duration from 7% to 11% which will affect crop yields in tropical regions. At current temperatures, small island nation states are already feeling climate impacts through sea level rise and where current storms increasingly render food production impossible after salt water intrusion onto food producing soil (Tschakert, 2015).

To achieve this new target of 1.5°C the current global carbon budget is reduced to 400 billion tons CO_2 and is one expected to be surpassed within four years of current rates of consumption. Glen Peters senior researcher at the Center for International Climate and Environmental Research (CICERO) interviewed at COP21, identifies a complication in that the shift away from fossil sources to negative emissions requiring burning biomass and capturing the emissions is one where the research is much further behind for this than expected[205] (McSweeny & Pidcock, 2015). Rogelj et al., (2016) in their analysis of INDC's post COP21 have concluded that the "flexible framework" that was established for it is too weak to keep warming below even the 2°C target. This weakness stems from pledges in carbon reduction past 2030, where if fossil energy

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[204] Australia's National Coral Bleaching Task Force released results on their survey on the Great Barrier Reef that disclosed bleaching has been found on all but 7% of the reef, with estimations of 60-100% severe bleaching in the northern half (ARC Center of Excellence Coral Reef Studies, 2016 April, 20).

[205] Around 80% of COP21 attendees surveyed at a side event hosted by Imperial College London believed that carbon emissions could be reduced to limit global warming to the 2°C target using existing technologies. When asked about meeting the more ambitious 1.5°C target, the same expert audience while optimistic, felt that current technologies were not sufficient and that energy efficiency, renewables and carbon capture storage (CCS) would all have to be developed and rapidly deployed (Levey, 2015).

consumption were to be maintained at the 2030 level, then global temperatures by 2100 could be expected to be in the range 2.6 to 3.1°C, with a significant chance of reaching 4.2°C higher. Even if all current INDC pledges are implemented, global GHG emissions will still be 33% over what is targeted for 2030 to remain below 2.0°C relative to pre-industrial norms and global temperatures could reach 2°C by 2050 (Watson et al., 2016). The weaknesses of current INDC pledges, pointed out in a recent analysis from the global Carbon Budget (2015) concludes that the combined INDC's from the EU, U.S., China and India will use all the emissions budget to stay below 1.5°C (see Figure 4.12), leaving almost no room for any emissions from all other nations to stay even below the 2°C threshold (Le Quéré et al., 2015).

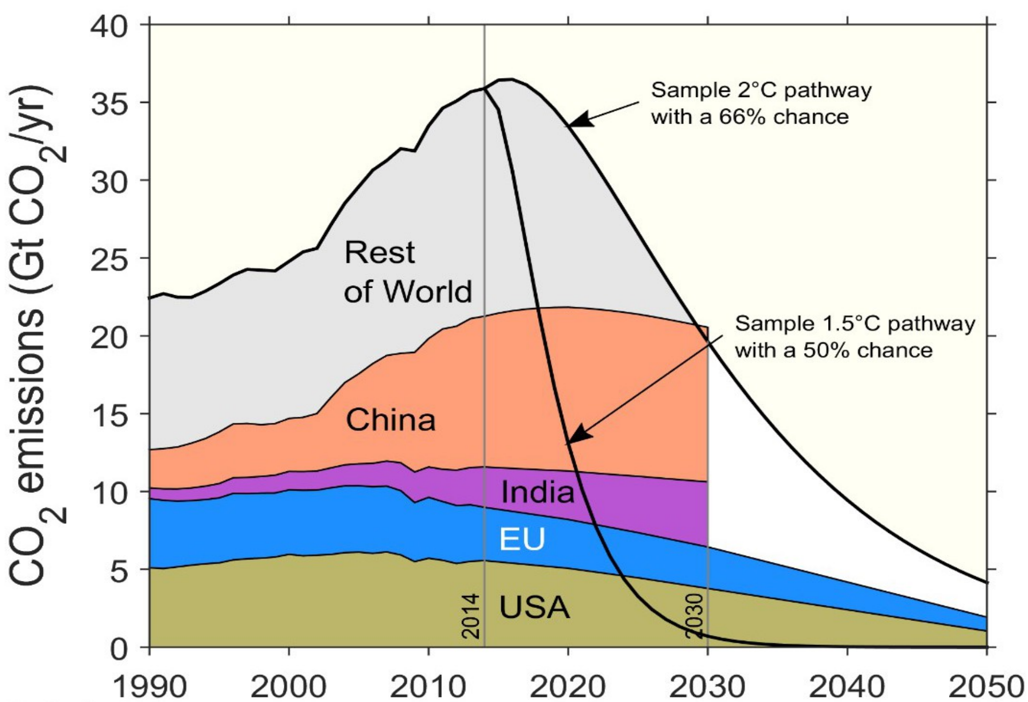

Figure 4.12 Edited graph by author Glen Peters illustrating how the INDC pledges from China, India, U.S. and the EU use up all CO_2 emissions to remain below a sample pathway to stay below 1.5°C and how most emissions are used to remain below a 2°C target (Source: Peters, Andrew, Solomon & Friedlingstein, 2015)

Prior to COP21, IPCC's most ambitious scenario projected a warming of 1.6°C above preindustrial. IPCC scenarios that approach the level required for even the 2.0°C warming limit all require some form of CCS and failure to achieve this might require global climate engineering (Dyer, 2009; McSweeny & Pidcock, 2015). In April, 2016, IPCC agreed to examine the consequences of 1.5°C levels of warming in its sixth report (Hulme, 2016). Prof Jim Skea, at COP21 believe what can hinder this from happening is the paucity of published research to create the report (McSweeny & Pidcock, 2015).

Fossil fuel reduction is a complex web of global factors with some of them being economic, political, business and military interests, climate change, infrastructure replacement, food, land usage and ecosystems. The 1.5°C target cannot be expected to be met without overshoot after which ways must be found for fossil fuel consuming civilizations to become carbon negative. Reducing fossil energy consumption is central to any policy or scenario and using market forces to alter consumptive behavior is considered key for developed countries to act on[206].

> The more likely situation, however, is that a specific climate target becomes unreachable much earlier ... because there are upper limits on sustained emissions reduction rates imposed by what the countries' economies can realize collectively given the present state of technology and infrastructure. Economic models estimate that feasible maximum rates of emissions reduction may not exceed about 5% per year (5). Under this assumption, the

[206] "Fossil fuel subsidy reform is the missing piece of the climate change puzzle. It's estimated that more than a third of global carbon emissions, between 1980 and 2010, were driven by fossil fuel subsidies. Their elimination would represent one seventh of the effort needed to achieve our target of ensuring global temperatures do not rise by more than 2°C. As with any subsidy reform, change will take courage and strong political will, but with oil prices at record lows and the global focus on a low carbon future – the timing for this reform has never been better." John Key, Prime Minister of New Zealand at COP21 (FFFsR, 2015).

1.5°C target had become unachievable before 2012, the 2°C target will become unachievable after 2027, and a 2.5°C target will become unreachable after 2040 (Stocker 2013, pp. 281).

Cap and Trade

Cap and trade originates from Montreal Canada, where in 1968 economist John Dales studying the Great Lakes region growing problem of acid rain and other pollutions[207], arrived at a market based solution of "tradable permits or allowances" (Conniff, 2009). Dale's tradable permits, core to cap and trade did not dictate to polluters how to restrict or reduce their pollution, rather it established a cap to be placed on carbon emissions. Industries would start each year with a quota of an allowable set of emissions where if these industries used less than their allotment, they would auction off their unused allotment into a pool for sale to those who exceeded theirs. Each year the allotment cap reduced resulting in an expected increase in the cost of unused allotments. In practice, cap and trade allowed governments to commit to carbon reductions using economic incentives to reduce industry's emissions with the hope that cap and trade will mimic its past success of reducing the Great Lakes industrial emissions of sulfur dioxide SO_2 and nitrous oxides NO_X[208].

> The economics of climate change is a problem from hell. Trying to do a benefit-cost analysis (BCA) of climate change policies bends and stretches the capability of our standard economist's toolkit up to, and perhaps beyond the breaking point (Weitzman, 2015, pp. 145).

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[207] Arthur Pigou (1920) was the earliest promoter of a pollution tax, that should be paid by both the producer and consumer for products causing unacknowledged costs to any individual not involved in the original interaction. Taxes such as the carbon tax are often called Pigovian Taxes.
[208] The year cap and trade took effect (1995), acid ran emissions fell by 3 million tons, exceeding expected results (Conniff, 2009).

Carbon Tax

Carbon tax differs from cap and trade in that it taxes emissions[209] to pay for real economic damages[210] caused by fossil carbon emissions (Ackerman & Stanton, 2010; Hope, 2015). In this setting, taxes are charged upon the consumer (households, business and industry) for the right to pollute[211]. This results in increasing costs of all fossil fuel sources and works to encourage adoption of alternate "green technologies and solutions". BP (2016) in their 2016 Energy Outlook, promoted that placing a "meaningful global price for carbon" as the most efficient way to grow GDP while reducing carbon emissions.

Hope, Gilding and Alvarez (2015) point out that placing taxes on "socially and economically damaging products" such as tobacco and asbestos have been historically accepted. With climate change being primarily caused by fossil energy consumption, the current practice of fossil fuel companies externalizing this cost can expect to have society react to recover these costs from regulation, taxes or carbon pricing. Both Parry, Heine, Lis, and Li (2014) and the OECD (2016) identify that globally, coal is taxed far too lightly to balance the externalized costs of its consumption and gasoline consumption is overcharged in some countries like the United Kingdom and Germany, yet subsidized in other countries such as Indonesia, Egypt and Nigeria. Overall, it is in the OPEC countries of Saudi Arabia, Venezuela, Iran, Algeria, Kuwait, Egypt

[209] This tax is measured in dollars per ton of carbon dioxide tCO_2 emitted. The tCO_2 per litre of gasoline = $tCO_2/425$ and per litre of diesel = $tCO_2/373$, where tCO_2 is the tax per metric ton.
[210] This is termed the Social Cost of Carbon, $SSCO_2$ and was estimated to be \$105 tCO_2 in 2008, rising to \$122 tCO_2 in 2012 (Hope et al. 2015).
[211] Peter Baylis (2015) argues that these costs should include non-market goods such as temperature where evidence estimates that individuals are willing to pay between 1% to 3% to avoid a 1°F summer temperature increase.

and Libya where the greatest externalized cost of fossil fuels presently occurs due to extensive subsidized domestic oil consumption (Parry et al., 2014).

While carbon taxes are relatively quick to put in place, challenges arise in calculating the monetary amount of the tax in the projected damages and whether it should be based on the energy delivered, reducing energy consumption or on the carbon content of the fuel consumed reducing carbon emissions and encouraging choice in fuels to be consumed (OECD, 2016). The U.S. EPA uses the Integrated Assessment Model (IAM)[212, 213] blending three tax models: Dynamic Integrated model of Climate and the Economy (DICE), Framework for Uncertainty, Negotiation and Distribution (FUND) and Policy Analysis of the Greenhouse Effect (PAGE)[214] (Ackerman and Stanton, 2012; IAWG, 2013). To date, only a handful of nations have been enacted or proposed carbon taxes (Carbon Tax Center, 2016). [215]

> We need an effective price on carbon emissions if we want to tackle climate change. Unfortunately, implementation of the polluter pays principle is woefully lacking. While lower-end estimates put the damage from emitting 1 tonne of CO_2 at EUR 30, 90% of all emissions from energy use are priced at less than that when we look at 41 countries

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[212] SEDAC provides descriptions of current IAM models being used by various research institutes. Further detail can be found at: http://sedac.ciesin.columbia.edu/mva/iamcc.tg/TGsec4.html

[213] Pindyck (2015) challenges the use of IAM's as too flawed to be useful for policy analysis, since they work to create an illusory perception of knowledge and precision. These models represent the informed opinion of IAM modelers rather than any form of a scientific consensus.

[214] Detailed descriptions of these models can be found from the following researchers: DICE (Nordhaus, 2008), PAGE (Hope, 2006) and FUND (Anthoff, Tol & Yohe, 2009).

[215] SFU environmental economists Jaccard, Hein and Vass (2016) point out that Canada needs to institute a base carbon tax of $30 per tonne of CO_2 and raise this tax by $15/year to $300 per tonne CO_2 by 2030 to meet its Paris commitment of reducing emissions 30% within 14 years and expect that it is unlikely that Canada's political leaders would risk doing so due to expected "severe political consequences."

representing 80% of world energy use. Moreover, 60% of emissions are not subject to any price whatsoever. We cannot continue like this if reducing greenhouse gas emissions in a cost-effective manner is a true policy objective (OECD, 2016, pp. 4).

Stranded Fossil Energy Assets

There exist multiple published carbon targets to meet a wide range of probabilities of remaining within 2°C [216] and 3°C climate targets. Summaries of the earlier models looking at restraining global temperature to below 2°C, dictated a range of emissions from 400 to 500 Gt from 2000-2015 (Allen et al., 2009; Meinshausen et al., 2009). This carbon budget was further updated by Leaton, Ranger, Ward, Sussams, and Brown, (2013) to 131 Gt CO_2 in identifying allowable emissions to remain staying below a 1.5°C target, 269 Gt (2.0°C), 310 Gt (2.5°C), 356 (3.0°C) respectively, where the first target of remaining below 1.5°C was expected to be breached by 2020 at current rates of CO_2 emissions (Le Quéré et al., 2015). Looking at all remaining fossil fuel reserves the investment analysts at Carbon Tracker (2011) concluded that roughly three quarters of all reserves must remain unconsumed, which were promptly classified as "stranded assets" and must remain unburned. The urgency of working to enact change is shown by the Carbon Countdown Clock (see Figure 4.13) which illustrate the number of years of current GHG emissions to the probability of staying below 1.5°C, 2°C and 3°C targets, from the date November 1, 2015 (Source: The Carbon Brief, 2015).

The founding position of Carbon Tracker's origin stemmed from financial concerns over shares of remaining fossil fuel reserves that were both business and state owned. If unburnable assets

[216] Johnson et al., (2015) conclude under the 2°C scenario that without carbon capture and storage, coal fueled electrical generation must be completely phased out with a rapidity dependent on the "implementation and stringency" of climate targets.

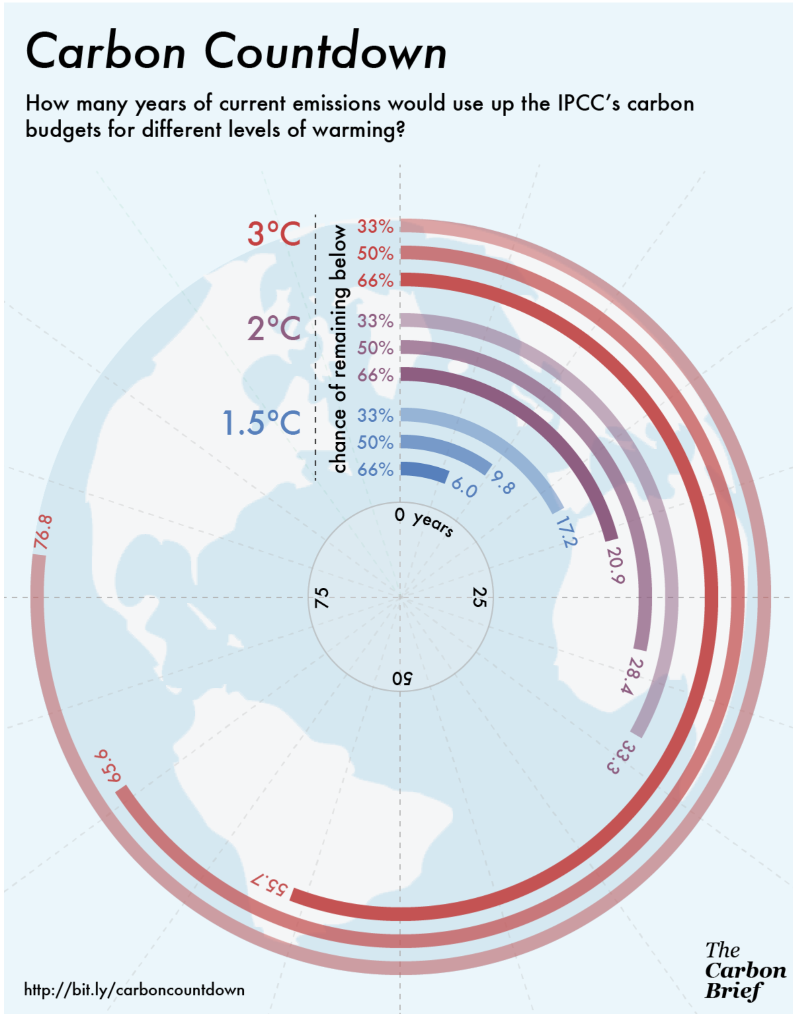

Figure 4.13 The Carbon Countdown (Source: The Carbon Brief, 2015)

were on the books, the business share of those reserves would be recognized as being substantially overvalued which would leave as much as 85% of an individual company's assets stranded[217] (Dominguez, 2014). It is in the analysis of the remaining carbon emissions from coal, gas and oil reserves (see Figure 4.14) it was concluded that 33% of oil, 50% of gas and 80% of coal reserves[218] must remain unused prior to 2050 to leave a 50% chance of remaining below

[217] Looking at it this way, the current glut of fossil fuel on the market has resulted from private and state pumping maximum levels before expected extraction restrictions set it.
[218] Carbon emissions from burning coal is triple the amount released by oil and quadruple of gas (Robins et al., 2013).

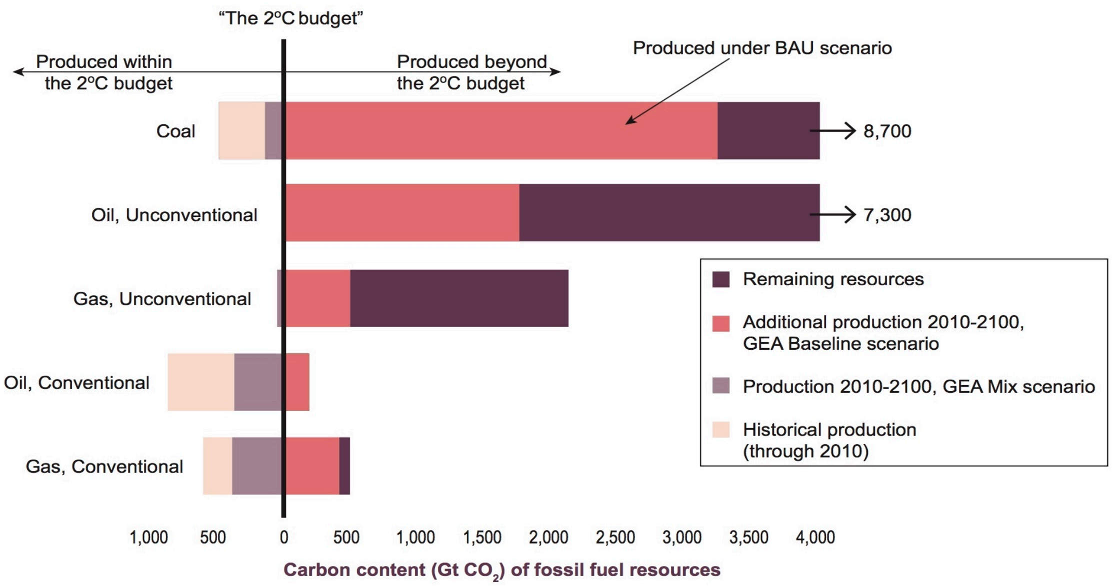

Figure 4.14 Using a Global Energy Assessment (GEA), five dominate fossil fuels were examined with the light pink bar showing historical consumption, the purple showing the collected carbon budget remaining to be consumed to remain under a 2°C target, the pink bar showing BAU consumption through to 2100 and the dark purple bar showing all remaining fuels after 2000. Consumption is assumed to remain steady at the 2012 level of consumption (Source: Lazarus and Tempest, 2014).

2°C[219] (Robins, Mehta & Spedding, 2013; McGlade and Ekins, 2015). The heaviest loss from all unburnable fossil fuel resources is expected to be shared between Canada and Venezuela[220] where 99% of remaining URR would be stranded (McGlade and Ekins, 2015).

[219] IPCC GHG stabilization scenarios found that no emissions were possible to have a 93% chance of remaining below 2°C and required that atmospheric CO_2 would need return to 350 ppm but could rise to 378 ppm if one wished to accept 90% odds.
[220] The latest numbers on global reserves can be found at the IEA International Energy Statistics site:
http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=57&aid=6&cid=regions&syid=2010&eyid=2014&unit=BB

HSBC (2013) believes that investors have yet to price in this near $20 trillion-dollar (US) stock valuation risk from stranded assets due to the long-term nature of proposed carbon reductions in meeting a 2°C warming target. It is these investors, that divestment programs are therefore directed by using both a moral and stranded assets position. Moral positions[221] have been used in the past targeting tobacco, munitions, adult services, gaming and apartheid regimes (Ansar, Caldecott and Tillbury, 2013). Fossil fuel divestment has recently become the focus of 350.org[222] and to date major divestment campaigns are ongoing at universities, colleges and religious institutions across the planet (Alexander, Nicholson and Wiseman, 2014).

While Ansar et al., (2013) expects only limited financial impact from divestment actions, an international group of 75 institutional investors managing over $3 trillion in assets started the Carbon Asset Risk Initiative (CAR) to engage the largest 45 fossil fuel companies to recognize and address the financial and physical risks of climate change (CERES, 2013). Despite stranded asset awareness, in 2013 fossil energy companies allocated $674 billion to explore for new resources that would remain unburnable which if continued at the same rate over the next decade, represents $6.74 trillion wasted in the pursuit of more unburnable resources (Leaton, 2012).

Rising costs of BAU growth caused GHG emissions from fossil fuel combustion dictates that the benefit from fossil fuel energy sources is declining and is increasingly against the majority

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[221] "The coal industry will be hated and vilified, in the same way that slave traders were once hated and vilified". Brian Ricketts, Secretary-General of the European Association for Coal and Lignite (Euracoal) in a message to Eurocoal members a few days after COP21. Retrieved January 3, 2016 from: https://euracoal.eu/cop21-us-outmanoeuvres-eu/

[222] 350.org started organizing in 2008 as a small group of students and Bill McKibben and rapidly expanded to 188 countries in the pursuit of restraining carbon emissions to prevent dangerous global warming. Further detail can be found at: http://350.org

interests to continue and/or encourage consumption. The declining quality of fossil energy sources when combined with rising negative externalized costs suggest that from multiple perspectives, energy descent reinforces a priority for educators that previous pedagogies supporting fossil energy consumption through consumptive lifestyles must be re-examined.

Chapter Five

Fossil Energy: Economic Factors

Economic growth is a function of energy consumption, full stop (Rubin, 2012)

John D. Rockefeller[223] the richest man in North American history, amassed a fortune estimated at $336 billion, (adjusted for inflation as of 2011) through his majority owned company Standard Oil. In 1911, Standard Oil was broken up into 34 smaller successor companies using the 1890 Sherman Antitrust Act that followed the earlier attempt of an antitrust judgment fining Rockefeller $100 million, about one third of its value at the time[224]. In 2012, the top 12 fossil energy companies that include Esso, Exxon, Mobil, Imperial Oil, Chevron, Amoco, and Marathon, held a combined asset wealth exceeding $2.04 trillion dollars,[225] exceeding the GDP of all but eight nations[226] that same year.

$$GDP\ (Y) = C + I + G + [X-I]$$

Where:

C = Consumption **I = Investment** **G = Government Spending**

[X - I] = Net Exports **with: X = Exports I = Imports**

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223 http://www.businessinsider.com/richest-americans-ever-2011-4

224 When Rockefeller heard of the judgement that broke Standard Oil into 34 different companies, he advised his golfing partner Father J. P. Lennon to go out and immediately purchase shares in these companies, sound advice, since the pieces became more valuable as individual companies (Chernow, 2007).

225 http://www.businessinsider.com/the-20-most-valuable-energy-companies-in-the-world-2012-1?op=1

226 http://data.worldbank.org/indicator/NY.GDP.MKTP.CD?order=wbapi_data_value_2012+wbapi_data_value&sort=asc

The value of energy resides in its ability to do work. It was the introduction of fossil energy that made the current industrial civilization possible, and in its role fossil energy has been greatly undervalued for the work it does. Consider the following: a litre of diesel or gasoline can power the average SUV five to eight kilometres, which could include an undulating landscape. How much would one must pay a laborer, to push, pull or drag this same SUV over the same path and how much time would this take? The cost of one litre of gasoline or diesel is less than an equivalent bottle of soda pop and significantly less than what the laborer would command. The stored energy of fossil fuels is significant, costing a mere fraction of comparative forms of labor and capable of doing work beyond human capabilities, such as air travel and space flight.

Human reality is that every day, civilization burns between 80-85 million barrels of conventional oil where each barrel equals around twenty-five thousand hours[227] of human labour. At the conventional oil peak of 85.3 MMbpd averaged during February 2011, 2.14 trillion hours of human equivalent work was being done every day meaning that the equivalent of 269 billion extra workers had been added to the global labor pool. North America uses about 20% of this labor and each Canadian and American received the rough equivalent of eight hundred energy "servants" helping them in their daily lives. This number is derived from just conventional oil so when the number of energy servants is adjusted for total unconventional liquid fossil fuels, coal, gas and nuclear, this number is more than 810 billion extra laborers[228]. Extended to include all

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[227] A lengthy discussion on the equivalency between human energy and petroleum energy by petroleum energy experts can be found at The Oil Drum: Europe. Further detail can be found at: http://www.theoildrum.com/node/4315

[228] Depending on initial assumptions (days and hours worked, etc.), ASPO authors gave estimations between 0.119 to 0.600 trillion energy slaves. Spreading this over the human populated areas gives us between 11,000 and 55,400 energy slaves per square kilometre. Further

the energy sources outside of oil, the average North American receives a rough equivalent of two thousand two hundred and thirty human "servants" helping in their daily lives.

Andrew Nikiforuk in his 2012 work "The Energy of Slaves" related this energy servant concept to earlier civilizations and the labors (energy) of human slaves used in running industry, farms and households. For modern civilizations, the numbers of energy slaves are staggering which for just transport alone, fossil energy runs an excess of one billion internal combustion engines (ICE) cars, trucks, buses, planes and trains (Partanen, Paloheimo & Waris, 2014). Nikiforuk (2012) has been struck that the challenges to decarbonize today's industrial society bear numbers of similarities to the efforts of early abolitionists to end the usage of human slaves.

Fossil energy has been used to replace the human laborer, noticeable in the increased energy consumption. An illuminating example is the food industry (see Figure 5.1) where the jump to automation during 1997-2002 became a trend weaving its way through all parts of the food system except in wholesale/retail (Canning, 2010).[229] Markussen and Østergård (2013) in analyzing the energy needs of modern Danish food production found that 1.0 carbohydrate units of food energy required 4.0 hydrocarbon units. Further, nutrients used in fertilizers and feed required an additional importation of 84% nitrogen, 90% phosphorus and 90% potassium into

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detail can be found at: http://22billionenergyslaves.blogspot.ca/2013/11/our-army-of-invisible-helpers.html

[229] Hertwich and Peters (2009) quantified the GHG food footprint for several nations finding the lowest for citizens of Malawi that released 0.18 tCO_2 per year for each person to the high of 3.72 tCO_2 each year for residents of Luxembourg. Canada's per capita share was 1.57 tCO_2 and the United States was 2.29 tCO_2.

Denmark to top up domestic supplies, leading these researchers to conclude that Denmark's food system was unsustainable from a food security perspective since it was heavily dependent

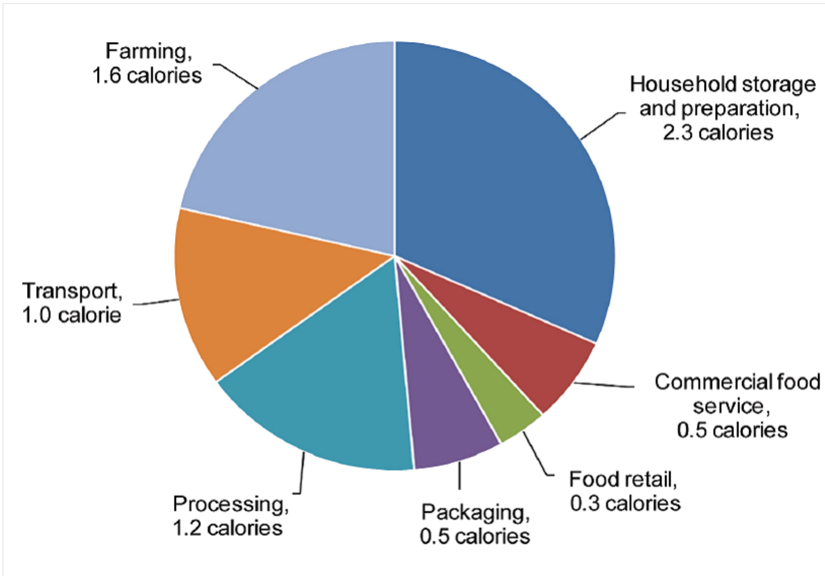

Figure 5.1 Current food consumption in North America is heavily dependent on fossil fuel consumption, where it takes an average 7.4 hydrocarbon units of energy to produce 1 unit carbohydrate of food energy from consumption (Source: Heinberg, 2009b)

on fossil fuels and "based on a non-circular flow of nutrients" (Markussen and Østergård, 2013). From the economic links between food systems to the expected volatile energy prices during any fossil energy descent, not only the price of food but also domestic food security will be affected[230] (Canning, Charles, Huang, Polenske & Waters, 2010).

[230] When Malthus made his predictions, he was unable to foresee the power of coal, oil and gas in turning hydrocarbons to carbohydrates (Rubin, 2012; Tverberg, 2013).

Conventional Energy Descent: Impacts and Concerns

Concerns over the future risks of energy descent are illustrated with a few graphs that outline some of the complex challenges. Transportation is 95% dependent on liquid fossil fuels, conventional oil, synthetic oils and liquid fossil fuel substitutes of propane, ethane and butane. Energy also correlates with the exponential growth in population over the past millennia, where population growth doubled since the discovery of coal in the mid 1860s and fivefold since the advent of fertilizer made from natural gas[231] in the 1950s, allowing Borlaug's Green Revolution[232] (Borlaug, 2000). If the link between human population growth and fossil energy consumption can be argued to be strongly correlated, then what happens to human population as energy consumption diminishes or collapses?

Past energy price volatility links not only spiking oil prices, but also spiking food prices which has in the past led to global food riots (Brown, 2011; Hsiang Burke & Miguel, 2013). Evidence of the impact of energy descent on food availability can be observed in the collapse of North Korean food production due to their loss of fertilizer derived from natural gas in 1993 (see Figure 5.2). Yields decreased to one-third of original production and required the aid of several nations to prevent massive starvation from occurring. Further concerns arise from the fossil fertilizer leaching essential nutrients from soils (Barak et al., 1997), that require years of restorative practices to return the soil to healthy yields of food production.

[231] Ramírez and Worrell (2006) estimate that fertilizer used in 2001 represented about 1% of global energy demand.
[232] The Haber-Bosch process of synthesizing ammonia is credited with allowing global population to exceed the 4 billion mark (Smil, 2011).

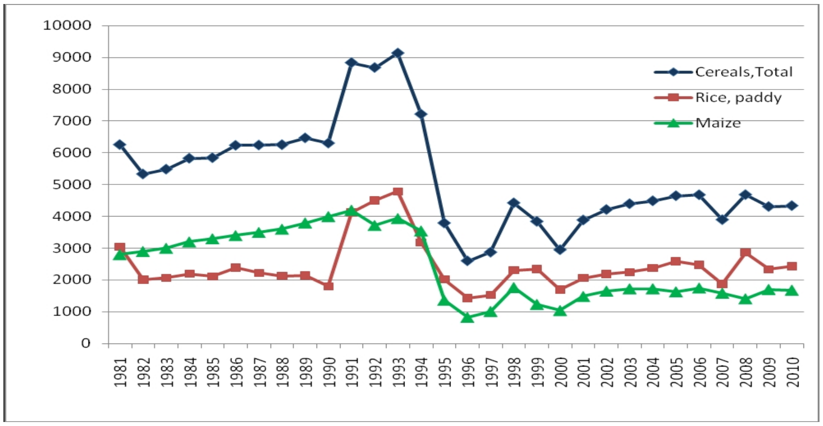

Figure 5.2 North Korean crop production showing a disastrous decline in yield stemming from the loss of fossil sourced fertilizer (Source: FAO, 2010)

Another illustrative example is the link between fossil energy production and all forms of plastic in modern civilization[233], the transport of food in providing nearly unlimited choice year around, the globalized economy, tourism, and a list of other outcomes that is nearly endless (Heinberg and Lerch, 2010). Energy use has introduced the complexities of a global market, where specialization has allowed for component production from different parts of the world to be transported to various global regions for assembly, then other regions for sale (Rubin, 2009). This complexity brings with it a lack of resiliency due to redundancies removed from the system to improve profit and efficiency (Tainter, Allen, Little and Hoekstra, 2003; Taleb, 2010, 2012).

> Historically, economic growth has been highly correlated with increases in oil consumption, and, aside from a few short supply interruptions, oil supplies have kept pace with growing demand. As a result, real gross domestic product (GDP) tripled in value while oil consumption grew by 40% from 1970 through 2008 (Murphy & Hall, 2011a, pp. 52).

[233] The amount of plastic that finds its way into the ocean is set to reach 250 million tonnes by 2025, or one tonne of plastic for every 3 tonnes of fish (McKinsey & Co., 2015).

Economic Links to Energy

Decoding the linkage between energy consumption and GDP growth is contested terrain (Hall & Klitgaard, 2012; Menegaki, 2014; Rees, 2015). Menegaki (2014) in a meta-analysis of 51 studies exploring the relationship between energy consumption and GDP, found numerous ambiguous and conflicting results due to "different: methods, sample periods, model specifications being employed, ... consumption patterns, presence of omitted variable bias, institutional, structural frameworks, ... policies followed by countries, sources of energy ... development stages and processes in each country" (pp. 32), leading him to question if results obtained reflected solely on the methodology being used. Four different streams of published research dominate the debate about energy consumption and GDP growth: (1) a growth hypothesis dictating energy leads growth that applies to increasing efficiency or developing countries; (2) a conservation hypothesis where growth leads energy consumption, indicating reductions in energy consumption can be obtained without harming GDP; (3) a neutrality hypothesis where energy consumption has minimal or no impact on GDP, also dictating that fossil energy consumption can be dramatically curtailed; (4) and a feedback hypothesis linking GDP growth to energy consumption as interrelated in what is classified as a bi-directional causality, where reductions in energy consumption will eventually lead to a reduction in GDP (Menegaki, 2014; Kalimeris et al., 2014). Conclusions based on these models is: first any developing country will be a GDP loser being unable to reduce energy consumption due to efficiency; second, nations can reduce fossil energy consumption to decrease GHG emissions with no hit to their GDP; and third that any reduction in energy consumption will harm their GDP.[234] Complicating this, BP (2014) data

[234] The correlation of energy consumption to GDP is significant and numerous data presentations can be found to demonstrate this linkage.

demonstrates declining growth in GDP from energy consumption indicates that in order to maintain constant GDP growth, energy consumption must accelerate (see Figure 5.3) despite all efforts to decouple energy from the economy. BP's position is contested by IEA (2015c) which showed the 2014 economy grew by around 3% while maintaining flat CO_2 emissions, which indicates the potential of a fossil energy economy decoupling.

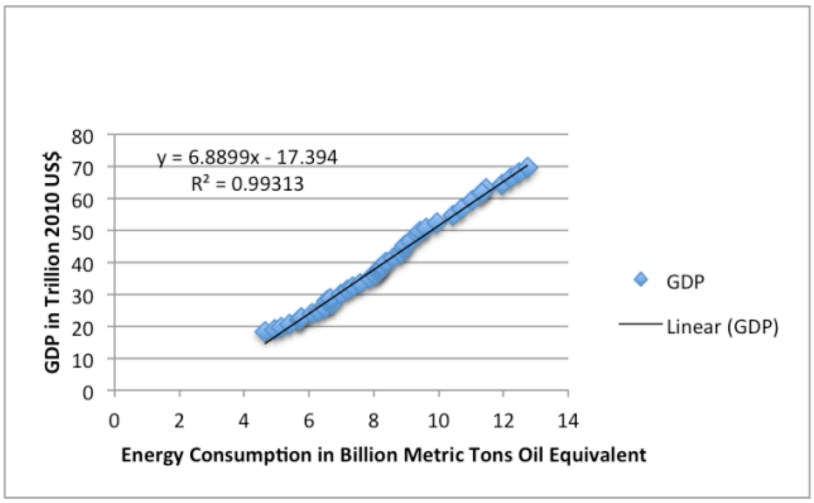

Figure 5.3 World GDP ($USD) compared to global energy consumption for the years 1969 to 2013 (Source: B.P, 2014)

Historical Oil Shocks[235]

Post World War II left western European nations dependent on Middle East oil in rebuilding following the division of Europe where the Soviet Union region contained the major oil and coal centers. Arab oil embargoes started with the Suez Canal Crisis in 1956 affecting Britain and France, in 1967 embargoing United States, Britain and West Germany but more notably it was

[235] "All but one of the 11 postwar recessions were associated with an increase in the price of oil, the single exception being the recession of 1960" (Hamilton, 2011, pp. 26).

the 1973 OAPEC[236] oil embargo and the later 1978-1979 Iranian Revolution where U.S. oil prices quadrupled and then doubled (Painter, 2012). Finding economic models that define the role of oil price shocks on GDP is contested[237] (Kilian & Vigfusson, 2014; Benes et al., 2015) but what is currently agreed is that oil price increases stemming from supply shocks will affect economic activity "after a significant lag" but would not affect economic activity if prices increased from consumptive demands (Baumeister and Hamilton, 2015).

Hamilton's, 1983 paper was the first to correlate that oil prices shocks, caused a significant negative impact on the U.S. GDP, a finding since confirmed by numerous researchers to also include major OECD and six non-OECD Asian countries (van de Ven & Fouquet, 2014). Data indicates that oil price shocks have a greater negative GDP effect than its positive reverse and that this negative GDP correlation is true for almost all industrialized and industrializing economies, including oil exporting countries (Mork, Olsen & Mysen, 1994; Archanskaïa, Creel & Hubert, 2012; Berk & Yetkiner, 2014). Using data investigating coal and oil usage on a developing economy from the last three hundred years from the United Kingdom, van de Ven and Fouquet (2014) concluded "that resilience of the British economy to shocks has changed following energy transitions, but does not appear to have been systematically improved by economic development" (pp. 28). Hamilton (2009) provides evidence that the 2007-2008 oil shock caused by strong demand and stagnating production when compared to previous oil shocks

[236] OAPEC stands for the Organization of Arab Petroleum Exporting Countries. Further detail can be found at: http://www.oapecorg.org/Home/About-Us/History

[237] Linear models of business cycles quantify a lower effect of oil price shocks to GDP than the larger role of some of the non-linear models (Kilian & Vigfusson, 2014). These researchers indicate that other factors such as financial stress, the oil share of GDP, consumer confidence and interest rate expectations may reflect increased vulnerability to oil price shocks.

caused by physical supply disruption, resulted in similar impacts to the economy affecting consumptive spending and automobiles[238].

Hamilton (2011) using data from the Arab Oil embargo in 1973, projects the risk of future economic fallout from an oil shock due to an exogenous decrease in oil would correlate to a greater economic loss in productivity, which could include rationing (see Figure 5.4). Supporting this was that the total market value of embargoed oil for the six months following September 1973 was less than $5.1 billion US, yet losses in the U.S. for 1974 Q2-Q4 amounted to $38 billion, which represented a loss of nearly an order of magnitude (Kilian, 2008). Hamilton (2011) further points out between September 1973 to July 1974, the consumption of energy related goods and services represented an increase of $14.4 billion, an amount less than half the decline. Ftiti, Guesmi and Teulon (2014) in their research, identified that it is exporting countries who are the most sensitive to oil price shocks and as such the ones that show significant impacts from global turmoil during either expansion or collapse situations.

Figure 5.4 Unused U.S. Gasoline Ration Coupons 1974
(Source: Smithsonian Postal Museum, n.d.)

[238] Plans for gasoline rationing in the United States in 1974. U.S. Federal Energy Administration: White Paper on Gasoline Rationing. Further detail can be found at: https://www.fordlibrarymuseum.gov/library/document/0067/7797944.pdf

Economic Implications of EROI and Net Energy

EROI and Net Energy are two metrics that project a hastened decline of energy available to industrial civilizations compared to the liquid fossil fuels production curve (Mohr & Evans, 2007; Martenson, 2010; Murphy & Hall, 2010, 2011a; Murphy, 2014; The Hills Group, 2016). According to some analysts, such as Murphy (2014) the net energy analysis of the production descent curve projects a severe decline in energy available to sustain civilization. While some might be quick to envision a Mad Max scenario in a collapse of civilization, one should point out that Mad Max was essentially a car chase, not a situation of fossil energy shortages. It should be noted that net energy analysis indicates that all activities revolving around the use of cheap fossil fuel will end faster than its decline in production as is shown in Figure 5.5 (Hall et al., 2009; Korowicz, 2011; Hall et al., 2014).

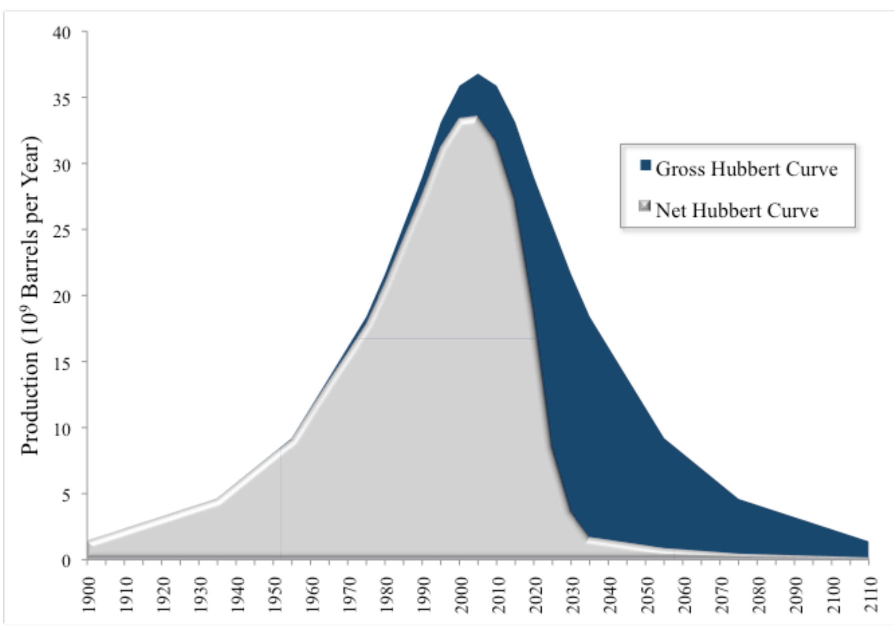

Figure 5.5 The net energy curve of conventional oil available for use in comparison to the Hubbert curve of conventional oil production (Source: Murphy, 2009)

Hall et al., (2009) in researching the question of “What is the Minimum EROI that a Sustainable Society Must Have?”, led them to estimate 10:1 as a level capable of supporting current western civilization, that 5:1 was the minimum to support a recognizable civilization and 3:1 could only sustain transportation and related systems.

As the quality of energy sources decline, the total energy production needed to maintain a constant net energy return must account for EROI. For an EROI of 10:1, to supply 10 units of energy requires that 11 units of energy be produced and for lower EROI energy sources such as corn based ethanol first calculated with EROI estimations of 1.6:1 to 1.2:1, to get 10 units of net energy would require the total production of between 26.7 to 80 units (Cleveland, Hall & Herendeen, 2006). In a later study using data from 1,287 counties across the United States, Murphy, Hall & Powers, (2011) estimated that corn-based ethanol had an EROI of 1.01:1, meaning that 1000 units of corn based ethanol energy need to be produced to provide 10 surplus units of energy meaning that a near zero-sum game had been reached.

The economic interpretation of declining EROI is that more fossil fuel must be produced to maintain a supply of constant net energy and since these fuels are more expensive to produce[239], the energy cost as a share of the economy must also rise. This also means that since the energy needed to produce these lower EROI fuels is increasing one can expect that emissions related to such production also increases externalized costs in GHG emissions. These lower EROI fuels are generally “dirtier” resulting in increased pollution further exacerbating negative externalized costs (Hatch & Price. 2008; Linnitt, DeMelle & Pullman, 2010; Stockman, 2013; Sovacool,

[239] EROI and producer prices are inversely and indirectly connected (Heun & de Wit, 2012).

2014a; Casey et al., 2016). Combining all these factors means that the demand for lower EROI fuels should increase as supplies of conventional fuels continue to decline, resulting in an increase in both the cost of production and negative externalities which work to tighten spending in the rest of the economy.

Three Eras of Conventional Oil

David Murphy and Charles Hall (2010) proposed that the age of conventional oil be separated into three eras with the first of these, the historical pre-peak era characterized by near perfect exponential growth in the production of conventional fossil fuel (see Figure 5.6).

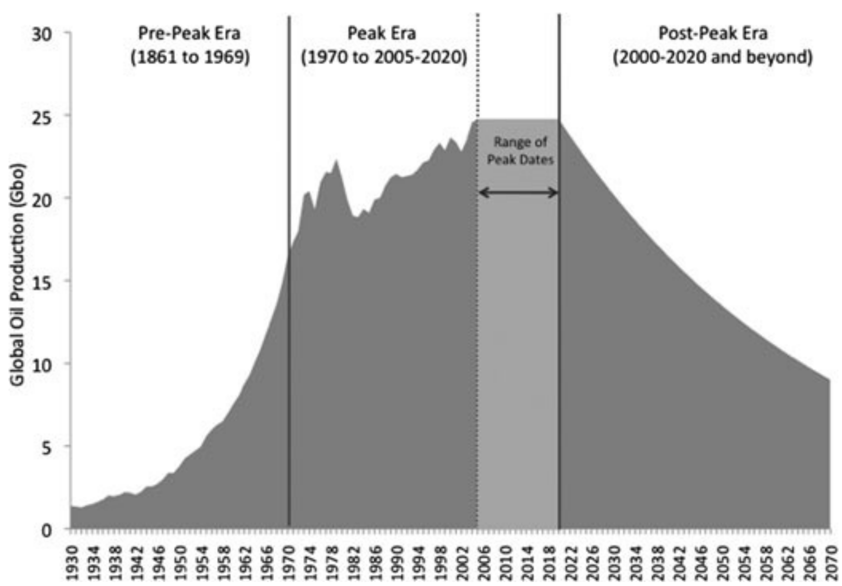

Figure 5.6 The ontological reframing of conventional oil defined by production curves (Source: Murphy & Hall, 2011a)

This pre-peak correlates to stable high EROI and is one that maintained an average price of around $23 U.S. per barrel[240]. Peak-era correlates to a number of current oil related events: peak

[240] Smith (2009) Classifies the pre-peak era from 1874-1973, as oil's golden era.

conventional production, conventional consumption exceeding discoveries, movements by governments to nationalize petroleum resources, fluctuating prices that averaged at around $43 U.S. per barrel and declining EROI. Post-peak conventional oil shows declining amounts of high EROI and increased substitution of lower EROI (and more expensive) unconventional fuel sources. If the economy continues to pursue a BAU trajectory, then Murphy and Hall (2011b) projected that oil consumption would follow an oscillating trend of decline with roughly 15 to 25 years of current consumption levels of high EROI conventional oil sources remaining. Heun and de Wit (2012) using non-linear least squares regression and "basic economic and physical assumptions" using the linear decline of conventional EROI were able to create a model matching the historic oil prices for years 1954-1996, and "correlated well" for 1997-2010. Their model projected that as the EROI decreased below 10:1, oil prices could be expected to diverge from the linear decline to correlative breakdown between both EROI and production costs and oil price (see Figure 5.7).

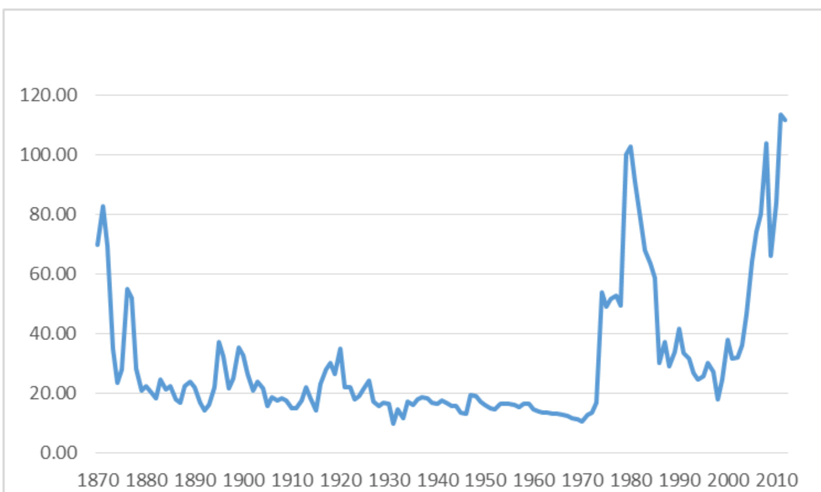

Figure 5.7 Inflation adjusted price of conventional oil (2012, USD) showing the approximate ninety-year stability of price until the U.S. reached peak production leading to several decades of increasing turbulence (Source: Hamilton, 2014)

This post-peak era will be forced to deal with a number of challenges, from declining EROI, diminishing conventional oil, needed transition to renewable energy sources, increasing debt accumulation, declining food production, global climate disruption, infrastructure replacement, aging populations, rising sea levels, migration away from coastlines, moving cities or building seawalls, declining growth where all of this is compounded by rapidly declining cheap conventional fossil fuels (Murphy & Hall, 2011b; Capellán-Pérez, Mediavilla, de Castro, Carpintero & Miguel, 2014, 2015; Murphy, 2014). In pre-peak, increasing oil consumption allowed one to "grow out of their problems" but as Murphy and Hall (2011b) state "using oil-based economic growth as a solution to recessions is untenable in the long term since both the gross and net supplies of oil has or will begin, at some point, an irreversible decline" (pp. 5).

Some Economic differences between Pre-Peak and Peak Conventional Oil

It is in the study of conventional oil's decline, Cassandra's and Doom-Sayers can be found peering into a fogged crystal ball, where each see a different sometimes competing variation of a post-peak era future. Links between global GDP and energy consumption are well established and demonstrate that fossil fuel importing economies thrive[241] with sources of cheap fossil fuels (see Figure 5.7) but stumble into recession once prices rise past a certain threshold (Murphy and Hall, 2011a, 2011b; Tverberg, 2011a; Hamilton, 2011; IEA, 2012; Arezki and Blanchard, 2014).

[241] For fossil energy importing countries, a drop in the price of fuel increases real income on consumption, decreases the cost of goods production, raises both profit and investment and lowers inflation (Arezki & Blanchard, 2014).

EIA (2015a)[242] data shows that the United States used an average 19.11 MMbpd of mean price $96.23/bbl[243] in 2014 equaling $0.671 trillion U.S. or 3.88% of the U.S. $17.3 trillion economy[244]. When oil was at an average or $20/bbl this would have represented 1.02% of the economy, meaning that the economy had an extra 380% increase to its petroleum energy costs in 2014. Research shows that fossil energy prices rise, money is reallocated from areas that previously added to GDP mainly due to discretionary consumption (Hall, Powers & Schoenberg, 2008; Murphy & Hall, 2010; Murphy and Hall, 2011a, 2011b). This 380% increase in energy cost must be compared to the 16.47% increase in disposable income[245] of the average U.S. citizen from 2000 to 2014, where at the onset oil was priced in the $20/bbl range. The total energy cost to the 2013 U.S. economy is higher than just these numbers, since energy is not only supplied by petroleum (36%) but by coal (18%), natural gas (29%), nuclear (8%) and renewables/biofuels (9%). As such the total energy cost to the U.S. economy rises to between 2.5 to 3 times greater than the 3.88% of petroleum alone. This is significant[246], since data provides evidence that once total energy costs rise above a certain threshold, i.e. approximately 10% for the United States, economic recession follows (Lambert et al., 2014).

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[242] EIA maintains a "frequently asked questions" energy data base that can be assessed at the following link: http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6

[243] The crude oil spot price is available from a number of sites such as: https://ycharts.com/indicators/average_crude_oil_spot_price

[244] The effect of high oil prices can be seen to "hit the GDP" when one compares this 1.02% to 0.21% of the U.S. GDP economy for $20 / bbl of oil.

[245] Disposable Incomes can be accessed at IBISWorldResearch at http://www.marketresearch.com/IBISWorld-v2487/

[246] "... policymakers and business leaders today have to take critical decisions on our future energy infrastructure in a context of unprecedented uncertainty ... uncertainties on future CO_2 prices, recession and energy prices continue to keep energy leaders awake at night ... We will be locked into the energy infrastructure that we build today for the next half-century-for good or for bad" (WEC, 2013, p.8).

Projecting Future Fossil Energy Consumption

Most literature relating economic growth and energy, define energy consumption as a function of development (Toman & Jemelkova, 2003). This is how major energy information sources such as the EIA's Annual Energy Outlook, WEC's World Energy Scenarios, BP's Energy Outlook, OPEC's World Oil Outlook, Exxon-Mobil's Outlook for Energy and IEA's Annual Energy Outlook base their future scenario projections of energy growth, in that demand drives the production of fossil energy supply. The importance of these scenario projections[247] is in their use by various agencies as a methodological analytic tool to deal with uncertainties of possible impacts and for use in policy design (Haasnoot & Middelkoop, 2012). Scenarios are used to explore alternate past, present and future developments, covering different resource assumptions, world oil prices and macroeconomic growth rates all which provide the resource to "analyze policy initiatives" using "policy-neutral baselines" (Haasnoot & Middelkoop, 2012; EIA, 2016b). These scenario projections for each particular set of assumptions and methodologies result in projections[248] of what might happen for each case, with a BAU future energy use projection generally defined as the Reference Case (EIA, 2016b). Varying, basic assumptions on economic, population growth, policy and technological developments are common shared features in the OPEC, WEC, BP[249], Exxon-Mobil, IEA and EIA BAU energy projections with

[247] Scenarios after making their appearance in military planning in the 1950's, have since been applied to environmental planning, both mitigation and adaptation to climate change and business development (Haasnoot & Middelkoop, 2012).
[248] Energy market projections are typified as have substantive uncertainty and are subject to unanticipated random events, technological developments, laws and regulations, along with demographic changes (EIA, 2016b).
[249] Columbia University Center on Global Energy Policy (2015) recorded in two interviews with BP Chief Economist Spencer Dale on the 2015 BP Energy Outlook projections. Link: http://energypolicy.columbia.edu/events-calendar/2015-bp-energy-outlook-2035-bp-chief-economist-spencer-dale

each placing various weightings on these and other inputs to their models. Differences are manifest in the foundations forming these projections; BP in discounting technological change is basically a status quo extrapolation, IEA includes environmental impacts of energy use, including the INDC commitments of various nations and EIA uses a market based approach of balance between supply and demand weighing price competition between various fuel sources (BP, 2015; IEA, 2015b; EIA, 2016b). All these energy projection scenarios carry alternate versions of a BAU base reference. For example, World Energy Congress (2013) compliments its BAU scenario of one focusing on energy equity through individual access and affordability through growth where one attains environmental sustainability through international policies and practices. The WEC (2013) scenarios clearly denote two futures: one for corporate driven neoliberal consumerist societies (BAU) and a democratic eco-socialist governance focusing on the cost of carbon emissions using technology to avoid paying greater externalized carbon costs.

The key projection of these scenarios is that the energy mix by 2050 will be predominately carbon based, a projection shared by Vaclav Smil (2015) from his geographical studies of human behavior and energy consumption. Transiting away from BAU energy consumption will take concentrated efforts from governing agencies in promoting increased efficiency and in dealing with resulting global economic challenges. In all BAU model's energy projections lead to higher fossil energy consumption and as such civilization's future will be increasingly challenged to live with the rising costs of GHG emissions[250].

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[250] Researchers exploring GHG emissions from BAU fossil energy projections, either look at emissions that can be eliminated from a zero or negative cost (representing inefficiencies in consumption that can be improved upon) or from the amount of emissions to be cut from the BAU baseline (Cline, 2011).

Kuznets Curve's failure to Reduce Energy Demand

Fossil energy equals great wealth and there lies the problem, for those who have wealth can be assumed to wish to maintain it which one might suspect is a major driving force behind BAU and ongoing resistance to efforts to reducing fossil fuel consumption. The linear correlation of personal wealth compared to per capita emissions means civilization needs a "Kuznets Curve of Decarbonation[251]" (von Weizsäcker, Smith, Desha & Stasinopoulos, 2014). While in theory, the environmental Kuznets Curve[252] should project a decline in pollutants such as per capita emissions, studies show that in rapidly growing countries, emissions overwhelm efforts to reign in pollution where these efforts are effective in wealthier countries experiencing slower growth (Stern, 2014). The logic of declining pollution resulting from increased affluence has since been championed by various agencies in promoting global growth and affluence (Figure 5.8) as the solution to reigning in various pollutants (Dinda, 2004; Stern, 2014). Evidence indicates that while some pollutions are reduced by rising affluence, others especially fossil CO_2 emissions have been found to increase (Arrow et al., 1995; Dinda, 2004; Stern, 2014). Dinda (2004) further indicates that no inflection point can be found linking per capita affluence with a reduction in pollution and that no link can be found between a reduction in pollution from rising economic growth.

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[251] Von Weizsäcker et al., (2014) is referring to the Environmental Kuznets Curve, named after Simon Kuznets (1955, 1963) who first proposed that an inverted u shaped curve represents the correlation between economic inequality and progression of economic development (Stern, Common & Barbier, 1996; Dinda, 2004; Stern, 2014).
[252] Prior to 1980's, it was thought that increasing economic affluence correlated with increasing environmental damage as was quantified by Ehrlich and Holden (1971) in their IPAT model where Impact = Population x Affluence x Technology (Stern, 2014).

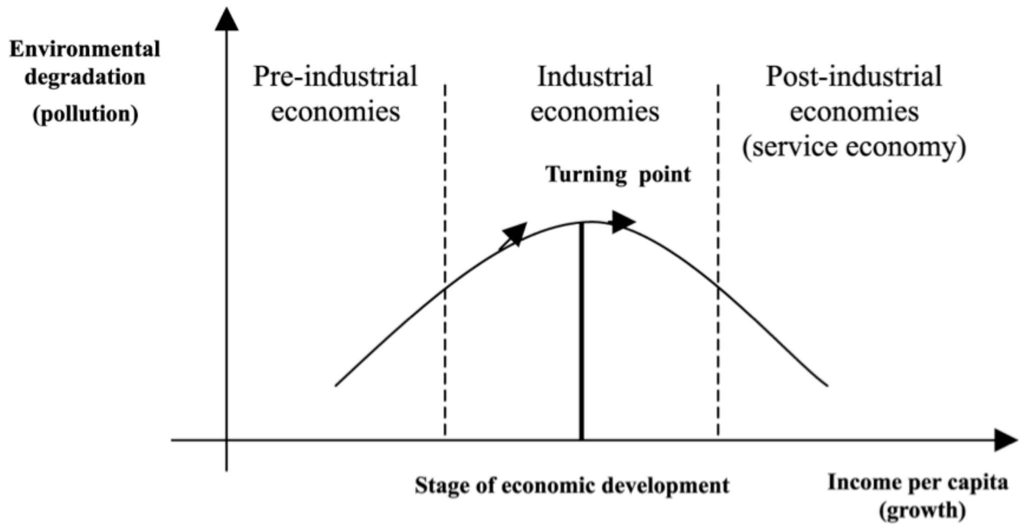

Figure 5.8 Environmental Kuznets Curve showing the projected reduction in environmental degradation as per capita income increases (Source: Figueres & Popova, 2011)

Arrow et al., (1995) further points out that economic growth does not represent a "panacea" to increase environmental quality, rather the main issue remains the content of the growth. Most importantly is that from this no evidence has yet been found to support a growth ontology that will reduce carbon consumption and decrease CO_2 emissions, instead increased affluence correlates to increased fossil fuel consumption[253].

[253] BP's Energy Outlook 2035 projects the greatest effect of decoupling GDP from fossil energy consumption stems from increasing efficiency and not the expected migration to natural gas from coal and oil consumption (BP, 2015).

Geopolitical Impacts that can Limit Exports

In 1973[254] [255] [256] and 1979 two oil crises occurred that resulted in oil price shocks and global recessions with both crisis originating from geopolitics (Hiscock, 2012; Klare, 2012). This concerns policy makers worldwide, since as smaller fields of conventional oil dwindle, the remaining largest giant fields continue to shrink oil production into the hands of nationalized oil company (NOC) fields in Middle East and North Africa (MENA) regions. The Arab Spring uprising, the threatened Iranian blockade of the Strait of Hormuz, Iranian sanctions, Iraqi insurgency, Syrian and Libyan civil wars, Saudi and Nigerian pipeline explosions and the growing Yemeni war with Saudi Arabia, represents turmoil in the majority of nationalized OPEC nations[257]. Any severe disruption in OPEC[258] would immediately spike oil prices and as in

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[254] In the 1973 Arab Oil Embargo the price of oil quadrupled from $3 to $12 /bbl, creating the deepest recession since the great depression some 40 years earlier. This resulted in four noticeable impacts: Oil consumption fell, A significant proportion of capital stocks and technology was mothballed due to the increased expense to operate, Marginal costs increased for manufactured goods and transportation fuels increased and was rationed (Murphy & Hall, 2011)

[255] Robert Hirsch (2012) at the ASPO 2012 convention provides a history of some of the domestic behavior resulting from the oil embargo that happened inside the US. Link: https://www.youtube.com/watch?v=QIWg6CyVKk0

[256] The U.S. responded to the Arab Oil Embargo by establishing the Strategic Petroleum Reserve, mandating a National speed limit of 55 mph and creating the IEA to monitor and predict global oil consumption and supply trends.

[257] OPEC's share of the oil market that has been moving between 28-36 MMbpd, represented 40% of the global oil production in 2010.

[258] "In early January 1948 Secretary of Defense James Forrestal warned that without access to Middle East oil, "American motorcar companies would have to design a four-cylinder motorcar sometime within the next five years." U.S. annual per capita oil consumption in 1948 was 14.4 barrels. In 2010 annual per capita consumption was 22.6 barrels, and the United States consumed around 19 million barrels per day. Had U.S. public policy, through the preservation of public transportation, the promotion of efficiency, and other measures (including four-cylinder motorcars), maintained the 1948 level of oil use, U.S. oil consumption in 2010 would have been almost 40 percent lower, with consequent benefits for the economy, U.S. security, and the environment" (Painter, 2012, pp. 38).

previous oil spikes should plunge economies into recession, and if severe enough, global recession (Hamilton 2011; Baumeister & Hamilton 2015).

In the neighboring continent, the U.S. International Security Advisory Board (U.S. ISAB, 2014) has described Africa as "the resource curse center" and singles out Nigeria as being "plagued by a complex brew of corruption, sector mismanagement, oil theft, and oil spills" (pp. 22). Terrorist and armed insurrections are significant in the amount of reduction to national petroleum production and exports from Nigeria, Algeria, Sudan and South Sudan (U.S. ISAB, 2014).

Export Land Model (ELM)

Brown and Foucher (2010)[259] in extrapolating the growing internal petroleum consumption of petroleum exporting nations realized that as production declined and internal consumption increased, these nations would reach a point where they cease to be a petroleum exporter (see Figures 5.9 and 5.10). The result of the decline of global fossil fuel for export impacts importing nations through diminished fossil energy available for consumption and exporting nations seeing a source of revenue decline.

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[259] Brown's theoretical model to the above left can be compared to Indonesian crude exports/imports to the right.

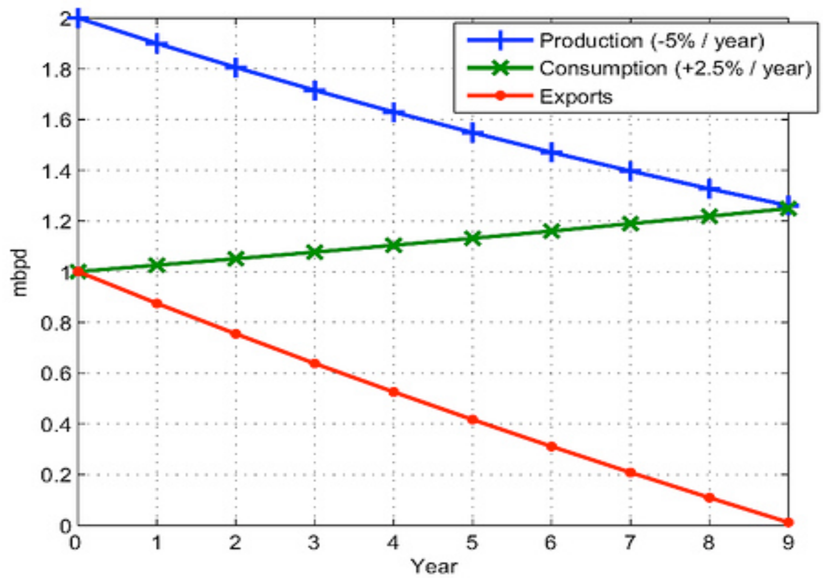

Figure 5.9 The export land model showing declining conventional production when combined with growing internal consumption leads to the rapid loss of conventional fuels available to be sold on the market (Source: Brown, Foucher & Silveus, 2010)

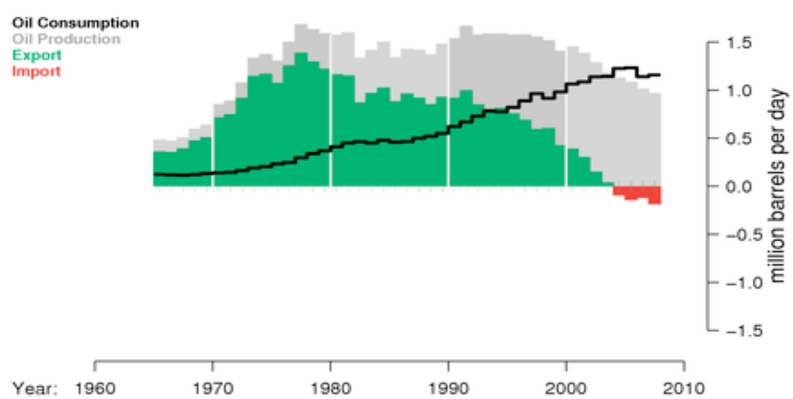

Figure 5.10 The export land model compared to the loss of Indonesian crude for export (Source: BP, 2008)

Fossil fuel imports and exports can significantly affect the overall economic balance sheet of both importing and exporting nations. For instance, EIA (2015a)[260] show that in 2014 net fossil fuel imports into the United States averaged 5.07 MMbpd at an average price of around $96.23 / bbl[261], costing $0.178 trillion U.S. or 1.02% GDP growth of the U.S. $17.3 trillion economy[262]. While high energy prices drain importing economies, and is reflected in their national GDP numbers, the loss of income from declining oil exports have even greater impact on all nations whose GDP is heavily dependent on their export[263].

Attempts to ensure energy security for oil exporting nations can be found in actions like the 2010 Saudi Arabia royal decree announcement that any new oil fields discovered in the future would not be developed but held in reserve for the benefit of future Saudis in future years (Hirsch, 2012). Decisions from major exporting nations like the Saudis, combined with rising domestic consumption of oil from these exporting nations, project a point in the future where there will be no conventional oil sold for export and that at a certain point in the future (see Figure 5.11), even previous fossil energy exporters might be in competition to purchase fossil oil fuels being sold on the open market (Rubin, 2009; Brecha, 2013).

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[260] EIA maintains a "frequently asked questions" energy data base that can be assessed at the following link: http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6

[261] The crude oil spot price is available from sites such as: https://ycharts.com/indicators/average_crude_oil_spot_price

[262] The effect of high oil prices can be seen to "hit the GDP" when one compares this 1.02% to 0.21% of the U.S. GDP economy for $20 / bbl of oil.

[263] In 2013, Prince Alwaleed the nephew of King Abdullah of Saudi Arabia, expressed his concern at their nation's dilemma in that after 30 years of attempts to diversify their economy away from oil sales the Saudi economy had remained 92% dependent on oil sales (Peixe, 2013).

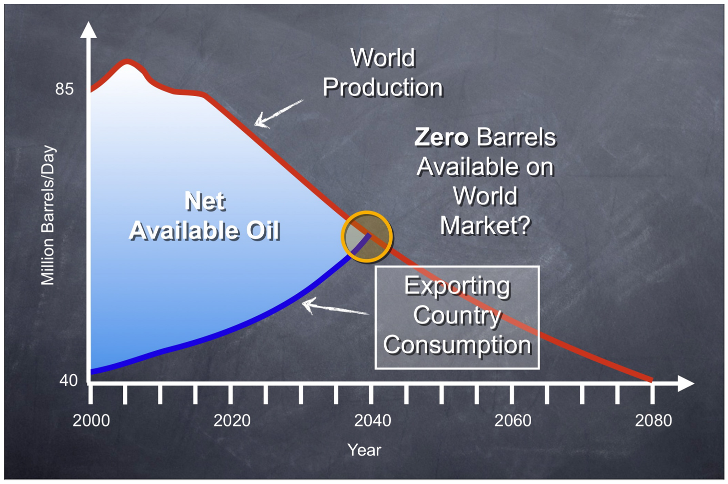

Figure 5.11 The decline in conventional fossil oil production contrasted to rising domestic consumption projecting the disappearance of conventional fossils for sale by 2040 (Source: Angelantoni, 2010)

Mismanagement of Resources that can Limit Production

Examples of government mismanagement are illustrated by the actions of Venezuela and Mexico that have caused a decrease in oil production for export. Venezuelan underproduction was a result from the syphoning of cash needed for future production and in Mexico, confiscation of revenues, substandard technology has led to significant declines in their production (Hirsch, Bedzek & Wendling, 2005). Great Britain can be described as the poster child of short sightedness for its fire-sale of oil reserves. In the mid 1970s to the early 2000s, Great Britain sold off close to two-thirds of its URR oil from the North Sea, the majority this oil realizing an average price of around $20/bbl. In 2006, Great Britain turned from a net exporter to an importer of oil in a world of $100+ barrel of oil.

Corporate mismanagement of resources for short term profits also impact the extent of resource that might be extracted. Washington State's Centralia Coal Mine is a classic example of this where seven of the ten seams of coal were not extracted but instead treaded as overburden and plowed back into the pit, shortening the life of the coal mine from 140 years to just 40 years to gain a 1% increase in profit for those 40 years (De Graaf & Batker, 2011). Continued attempts to maximize short term profits later led to the early closure of this mine due to slope instability, resulting in a loss of 650 jobs leaving a community concerned that they will pick up the costs to clean up the damages left (De Graaf & Batker, 2011).

Liquid Fossil Fuel Replacements[264]

All energy sources have trade-offs: biofuels having reduced energy density, requiring larger fuel tanks due to their lesser energy density[265], electric cars need electricity where the main source is coal or natural gas (Brecha, 2013). Biofuels typically have low EROIs, making them a poor choice, unsuitable to be used, unless heavily subsidized through economic policies or by other fossil fuels (Basset, Kermah, Rinaldi & Scudellaro, 2010; Murphy et al., 2011; McPhail & Babcock, 2012).

Canadian synthetic oil from Alberta bitumen, another liquid fuel source is politically contested where the former Harper government aggressively pushed forward development of Enbridge and Keystone pipelines to export the heavy synthetic crude to Texas and China. Numbers officially

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[264] One excellent online source that can be used to help explain the energy of renewables and the problems of substitutions: David MacKay (2009) *Sustainable Energy-Without the Hot Air*. Further detail can be found at: https://www.withouthotair.com/download.html

[265] Biofuels and natural gas liquids and biofuels have volumetric energy densities that are 60% of conventional crude oil (Brecha, 2013).

projected by Canada targeted 5 MMbpd by 2030, intended to supply Canada and the U.S. with a significant amount of liquid fuel production[266]. While this plan was met with multiple protests and blockades, the turbulent global collapse in oil prices from total liquid fossil fuel overproduction has caused much of the Canadian bitumen mining to be shut down[267].

Understanding the rise in global production of liquid fossil fuels is a blended number of conventional, condensate, bitumen, natural gas liquids and biofuels that work to confuse the global energy scene since these products are used differently from conventional oil. Condensate as a very light and volatile liquid produces very little diesel which when included in liquid fossil fuels production numbers is much like an owner needing a store inventory about the amount of kiwi on the fruit floor is instead given a number that includes all fruits. The problem of this is the growth of liquid fossil fuels combines the plateau of conventional oils from 2004 and unconventional liquid fossil fuels, meaning that infrastructure and engines built to use conventional fuels need be retired, retrofitted or abandoned. This challenges the argument that a peak in fossil energy production has not been reached since substitutions have been found allowing for the continuation of a BAU economy (Brecha, 2013; Livingston, 2014).

If one is to google "U.S. Energy Independence", then they will run into a multitude of reports in the news that both state and deny that energy independence will occur in short order. Officially,

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[266] 5 MMbpd out of the identified 43 MMbpd by EIA (2009) represents around 12% of global supply.

[267] Energy articles carried by Reuters early in 2015 can be found of refiners rejecting a 50/50 blend of fracking condensate and bitumen (termed "*dumbbell crudes*") that flowed like conventional oil but was critically deficient in distillate product content defining it as "a toxic blend that didn't meet their output requirements" (Taggart, 2015).

energy reality as stated by the 2014 report from the U.S. International Security Advisory Board (ISAB) is illuminated from their recommendations section at the back:

> Retire references to energy "independence" or "self-sufficiency." These terms describe implausible or undesirable energy market end states. Even with the growth in fossil fuel production and increased use of renewable energy, "independence" for the United States will not be possible in any meaningful economic or political sense. Use of the term creates unrealistic expectations at home, distracting from genuine policy issues (pp. A-1).

And further on in their recommendations ...

> The Department and broader Administration should reinvigorate and refocus efforts to advance fossil fuel subsidy reform. Fossil fuel subsidies are often pernicious, exacerbating energy overconsumption, underinvestment in domestic production, and market distortions, while undermining individual countries' fiscal stability (pp. A-3).

> Addressing the risk of climate change demands far-reaching reforms to the energy sector, even with the recognition that this will take many years to achieve and will require daunting efforts by the United States and many other countries. Climate change is an urgent threat to national and global security, and energy is its largest driver. Existing policies, at home and abroad, are inadequate to mitigate the large social costs of growing fossil fuel use (pp. A-4) ... Ultimately, economy-wide energy policies-especially a carbon tax-will be necessary to address negative externalities in a comprehensive and economically rational way (pp. A-4).

Liquid fossil fuels the most energy dense, easily portable energy source of all fossil fuels have come to dominate all other fuels as the choice for transportation[268]. Jeff Rubin, the former chief economist at CIBC, who was one of the first predicting major price hikes in oil prices back in 2000, bluntly states his economic perspective on the global dependence of oil: "the world is about to get a whole lot smaller." Rubin frames this view from his analysis projecting that fossil energy is going to dramatically increase in price, making everything dependent on fossil energy more expensive. This will alter all dynamics of globalization as a mover of goods and resources, simply because "distance costs money". This view indicates a future retrenchment of globalization back to one of localization, where future industries will most likely be regionally located industries (if they are still needed) or simply, the days of oceanic transits of containers filled with rubber duckies and other bathtub toys shipped around the world are numbered[269].

CAPEX and the Future of IOC's

Financially important to resource extracting companies is their capital expenditure or capital expense (CAPEX) needed for drilling, exploration, production and lease payments (Rook & Caldecott, 2015; Deloitte Center for Energy Solutions, 2016; Stevens, 2016). Due to the increased complexity of the remaining undeveloped fields and plays, CAPEX costs continue to rise requiring carefully budgeting that allow for best returns (EIA, 2010; Weijermars, 2011; Deloitte Center for Energy Solutions, 2016). This budgeting is challenged from both a "sunk cost

[268] Most alternative energy sources produce electricity and are not substitutable for oil. The fate of global transportation is at high risk from any enduring price hike in oil (Fantazzini, Höök & Angelantoni, 2011).

[269] In 1992, severe storms caused a transoceanic cargo ship headed to Tacoma, WA from Hong Kong, to lose 12 containers, one which held 29,000 plastic toy animals such as rubber duckies. These bathtub animals were quickly used in numerous studies for ocean current research (Ebbesmeyer & Ingraham Jr., 1994).

fallacy" where companies continue to expend significant funds on projects they are heavily invested in and "planning fallacy" in their underestimating the time to complete projects (Rook & Caldecott, 2015). With global fossil sales returning fuel prices below the cost needed to maintain production[270] which for smaller companies has reduced CAPEX (7% drop in CAPEX for 2013-2014) required for exploration forcing them to either shutter, add on extra debt[271] or sell off assets (Weijermars, 2011; Arezki & Blanchard, 2014; Deloitte Center for Energy Solutions, 2016). Debt however is increasingly problematic for the U.S. energy sector according to Justine Underhill (May 17, 2016) in reporting that in the first quarter of 2016, over 86% of the operating profits from the energy sector were used to meet interest payments on debt, where the debts maturing in 2017 are roughly fivefold greater than in 2016, increasing tenfold in 2020. It is this combination of un-repayable debt and lack of CAPEX funds that is exacerbating an increased risk of production collapse which are expected mainly from unconventional sources having faster depletion rates and higher costs of production.

Carbon Tracker (2015) from an investment perspective, sees the reduction in CAPEX as an opportunity to reduce expenditures on high cost projects and instead recommends increasing

[270] "Oil prices simply aren't going to rise fast enough to keep oil and energy companies from defaulting. Then there is a real contagion risk to financial companies and from there to the rest of the economy." (Jason Schenker (2016), President and Chief Economist at Prestige Economics).
[271] "By our calculations it will require additional debt formation of $39 trillion over the next decade to keep petroleum production operating. Where that funding will originate from, when it is very unlikely to ever be repaid, will be of tantamount importance. It will take very strong-willed societies to make such sacrifices. If those sacrifices are not made, the integrated global production system will have disappeared by 2026. 2016 will be witness to the beginning of this event with dramatically increasing closures and bankruptcies throughout the world's petroleum industry." The Hill's Group, 2016 in Peak Oil Review January 4, 2016, Retrieved January 6, 2016 from: http://peak-oil.org/perspective-of-an-association-of-consulting-petroleum-engineers-and-professional-project-managers-on-the-global-oil-industries-financing-perdicament/

dividends to shareholders and actively buy back shares. This follows on the heels in their recognition of "stranded carbon assets" where the fossil fuel industry risks becoming the "Kodak" company of the future which lost 98% of its share value in the space of two years due to the advent of digital photography. In the same vein, the global need to radically reduce carbon emissions within a generation and requiring renewables to rapidly scale upwards can be overlaid with the resistance of fossil energy companies to predict a timeline for demand destruction of fossil fuel from which there will not be an expected recovery (Carbon Tracker, 2015).

Oil companies are characterized as either an International Oil Company (IOC) or a National Oil Company (NOC) where the IOC's have come under increasing scrutiny for using an older business model poorly suited to deal with unburnable carbon and failing to handle the 2014 collapse of crude oil prices (Stevens, 2016). Stevens (2016) faults this business model from the IOC need to increase reserves to meet their "assumed increasing BAU fossil fuel demand" in a world of projected scarcity. Berman (2016a) and Bardi (2014) counters Steven's vision of fossil fuel abundance from concerns over a projected future scarcity of cheap oil where there is an abundance of too expensive to burn oil remaining to be consumed due to both rising production and externalized costs. As Berman (2016a) points out "Peak oil was always about running out of cheap oil".

The current global collapse in fossil fuel price has not only caused financial challenges to the IOC's but to NOC's as well. At world prices below $40 per barrel oil, every OPEC nation is experiencing a shortfall in revenues to balance their budget (see Figure 5.12), having lost $390 billion USD from expected revenues in 2015 alone (IMF, 2016). This revenue collapse is

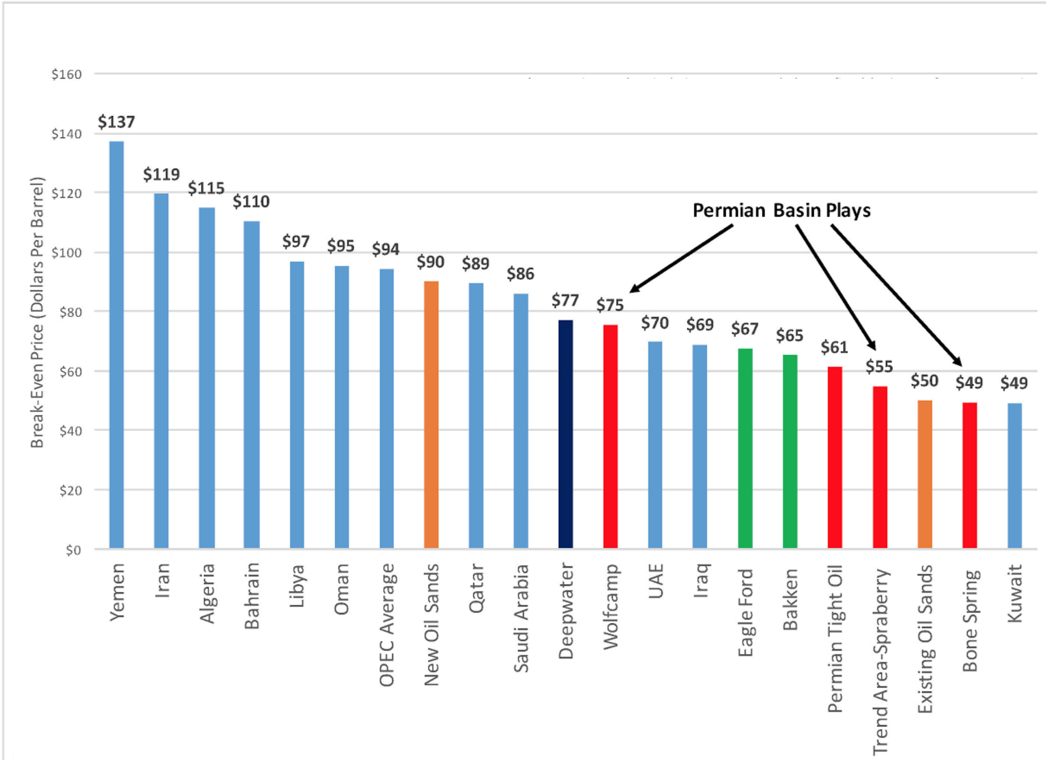

Figure 5.12 Projected Break Even Oil Price for OPEC and Unconventional Resources for 2016 (Source: Berman, 2016b)

complicated by an expected 10 million domestic young males looking to enter into the labor force in the next five years, where past dependency on fossil fuel industries has not led to diversification of their economy (see Figure 5.13). Economic diversification has shielded oil exporting countries like Canada, Norway, Malaysia and Indonesia but others, mainly OPEC nations have been forced to draw heavily from saved financial reserves (Dabrowski, 2015). For nations, having limited financial resources and large committed expenditures, the lack of diversification away from fossil fuels and collapse of fossil fuel prices have created serious economic challenges (Hutt, 2016). These current and emerging conditions present difficult, challenging decisions for all concerned.

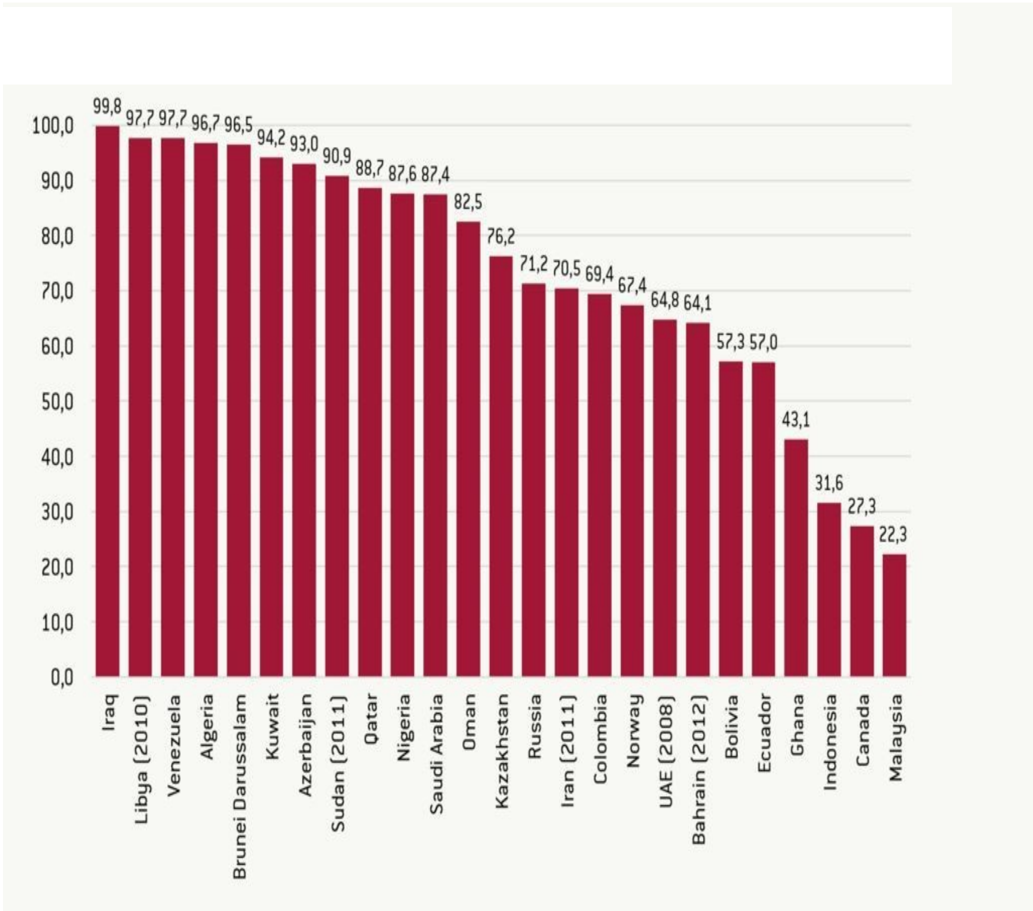

Figure 5.13 Exports of fossil fuels compared in percentage to the exports of merchandise for 2013. Alternate years are noted (Source: Hutt, 2016)

Chapter Six

Options & Obstacles to Altering Fossil Energy Consumption

> I maintain that the deflationary contraction underway worldwide is largely due to the fact that the world has run out of a particular form of oil: affordable oil. Turns out the peak oil story is still true, just playing out differently than a lot folks predicted. We're at the mercy of a pretty basic equation: oil over $75-a-barrel destroys industrial economies; oil under $75-a-barrel destroys oil companies. There is no "just right" Goldilocks place on the gradient (Kunstler, 2016, January 4, para. 16).

Industrial civilizations are facing growing numbers of crises in attempting to maintain a BAU economy. Increasing demand for fossil fuel energy has necessitated increasing amounts of unconventional fuels, where these fuels require substantively higher costs to produce than conventional fossil fuels. These unconventional fuels also do not provide required blends of oil to produce specialized fuels such as diesel, since their API densities[272] are either too light (shale oils) or too heavy (kerogen shale oil and bitumen SCO).

API gravity = [141.5/specific gravity] - 131.5

Economic growth, increasingly funded by debt, has borrowed financial resources from the future to pay for today. Furthermore, increasing negative externalized costs from fossil energy consumption continue to grow which diminishes the net benefit of consumption. The economic

[272] API (API gravity) is a measure of how light or heavy a liquid fossil mineral compared to water, where a measure above 10 means the petroleum product floats and below 10 sinks.

model of increased consumption is under assault from multiple factors and as attempts to maintain or increase growth are running into resources, financial and environmental limits. The question is what do we do now.

GDP: A Measure of Well Being?

The statistical significance relating GDP growth to energy consumption can lead one to question various nations commitment in their actions to reduce fossil energy consumption. Considerable effort has been made in attempts to decouple the economy from fossil fuel consumption but the success of this is contested. Foremost is the challenge in measuring the health and growth of the economy where economic growth metrics should be qualified with indicators that also measure social and ecosystem health. It is in this vein that GDP, the current measure of economic wellbeing is criticized, not in what it is measuring in the economy, rather in what it fails to measure (Stiglitz, Sen, & Fitoussi, 2010a; Kubiszewski et al., 2013; Coyle, 2014). Evidence supports that raising the global income of nearly one billion humans trapped in the extremes of poverty would greatly improve their quality of life through improved access to food, water, shelter, health and education indicating the need to target GDP impoverished nations (Helliwell, Layard & Sachs, 2013). Yet, at the high end of GDP nations, such as the United States, raising the GNP[273] per capita by a factor of three since 1960 has not resulted in a happier nation, rather it has increased afflictions of affluence such as obesity, adult onset diabetes, increased psychological disorders, loss of community and importantly the misery resulting from their

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[273] GNP (Gross National Product) presented to the U.S. Congress in 1934 by Simon Kuznets was the precursor to GDP which was developed at the Bretton Woods Conference, 1944 (Costanza, Hart Kubiszewski & Talberth, 2014). GNP's advantage over GDP is that GNP can be used to illustrate the consumer buying power of an individual and be used to estimate the average wealth, wage and ownership distribution throughout a region (Diffen.com, n.d.).

globally exported waste GHG emissions from increased fossil energy consumption and pollution challenges to be borne by all nations and populations, both rich and poor (Helliwell et al., 2013). The question arises therefore, how does one decouple the ontology of needed continued growth for GDP where it clearly does not benefit the GPI[274] of the population after a certain level (see Figure 6.1) and acts to counter those benefits by creating greater problems and challenges? (Brown & Ulgiati, 2011; Kubiszewski et al., 2013).

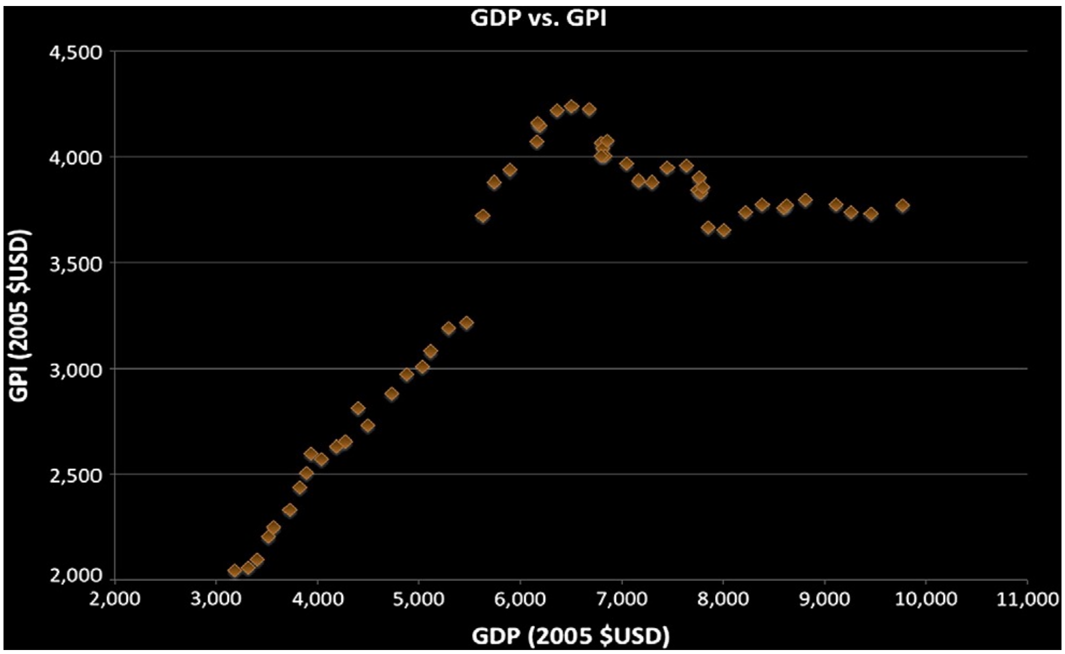

Figure 6.1 GDP and GPI per capita correlate strongly until about $7000 USD ($R^2$ = 0.98) after which they diverge negatively with a correlation (R^2 = 0.65) (Source: Kubiszewski et al., 2013)

In developing the concept of GDP, Simon Kuznets in 1934 warned against its usage as a measure of human welfare, yet it has since become the standard for measuring a country's overall economic and social health (Costanza, Hart, Talberth & Posner, 2009; Stiglitz et al., 2010a;

[274] GPI or the Genuine Progress Indicator distinguishes itself from GDP in how it classes different economic activity as either a cost or a benefit. Crime, pollution, disasters all count as an economic benefit under GDP but are classified as costs under the GPI index.

Kubiszewski et al., 2013). One contested metric of GDP is that it counts as benefits oil spills due to the need for cleanup and restoration, climate change impacts with the need to rebuild after violent unseasonal storms or to rebuild for mitigation and adaptation, lumping all under the umbrella of "social costs, environmental impacts and income inequality" with all linked to fossil fuel consumption (Costanza et al., 2004, 2014; Kubiszewski et al., 2013).

Coyle (2014) in looking beyond the GDP metric concluded there are three different indicators that must be measured by society: economic activity which she believes is well measured by the GDP, human welfare or wellbeing which could be measured by a "dashboard" of multiple indicators measured and lastly, measures of environmental, natural, infrastructure and physical capital. From the introduction of the Gross National Happiness (GNH) in 1972, there have since been multiple indicator measurements proposed:

- State of the Future Index (SOFI) ... The Millennium Project (1988).
- Index of Sustainable Economic Welfare (ISEW) ... Daly and Cobb (1989).
- Human Development Index (HDI) ... UNDP (1990).
- Ecological Footprint ... Rees and Wackernagel (1992).
- Wellbeing Index (WI) ... IUCN (1994-96).
- Genuine Progress Indicator (GPI) ... Daly (1996).
- Living Planet Index (LPI) ... WWF (1997).
- Human Poverty Index (HPI) ... UNDP (1997).
- Environmental Sustainability Index (ESI) ... Yale and Columbia (1999).
- Environmental Vulnerability Index (EVI) ... SOPAC and UNEP (1999).
- Dashboard of Sustainability ... UNCSD (2000-2001).
- Happy Planet Index (HPI) ... New Economics Foundation (2006).

(Nováček & Mederley, 2015)

The need to move away from GDP is essential for governments to wean their economic policies away from growth[275] and in turn from efforts to increase GDP linked energy consumption. Renewable energies, while growing have failed to replace fossil fuels, rather they have only added into the global increase of energy consumption. Recent declines in coal consumption appears to be one in the movement towards fracked natural gas where the growing abandonment of coal consumption is being hailed as a climate change breakthrough. Despite this apparent success, fossil fuel consumption remains stubbornly coupled to economic growth.

BAU Growth

Critical analysis can be of use to evaluate benefits gained from the taxpayer bailout to rebuild the U.S. economy after its crash in late 2008 using the United Nations (CASSE, n.d.) rubric in identifying five types of uneconomic growth:

- Jobless growth, where the economy grows, but does not expand opportunities for employment.
- Ruthless growth, where the proceeds of economic growth mostly benefit the rich.
- Voiceless growth, where economic growth is not accompanied by extension of democracy or empowerment.
- Rootless growth, where economic growth squashes people's cultural identity.
- Futureless growth, where the present generation squanders resources needed by future generations.

The recent movement of the U.S. and EU economy over the past two years for example, has been jobless, ruthless, voiceless and futureless. The U.S. and EU has surged in four of the five metrics

[275] Key discussions that questioned economic growth were not brought up at COP21 which Alexander (2016) interprets to be that the precondition for a safe global climate is continuous GDP growth, a paradigm that remains central in "mainstream political and economic discourse."

of uneconomic growth, which bear darkened prospects of the future trajectory of the western world in an energy descent. Several questions arise from this: What role is higher education playing in this unfolding of uneconomic growth in North America, and how can one justify any educational system that appears to be locked in step to supporting uneconomic growth?

> The richer countries of the world do not have the choice of growing their economies or de-growing them. A declining fossil energy supply will force degrowth upon them whether they want it or not and their only choices will be about the way they handle the contraction. The present parlous state of the world economy is a mild foretaste of what is to come if they make the wrong decisions (Douthwaite, 2012, pp. 187).

Growth vs Degrowth

Evidence supports the possibility that Western nations might have entered a prolonged recession, facing ecological limits, high levels of debt, reducing investment potential within and the movement away from centers of mature economies (Rockström et al., 2009, 2013; Kallis Martinez-Alier & Norgaard, 2009; Kallis, Kerschner & Martinez-Alier, 2012; Barnosky, Ehrlich & Hadly, 2016). Kallis et al., (2012) in their analysis of this, points out that growth economies are structured so that they do not know how to degrow, rather they will collapse.[276]. The concept of degrowth[277] first appeared in print around 1972, later in a conference in Montreal Les en-jeux de la décroissance (the challenges of degrowth) followed by French activists joining together in 2001 'Décroissance', 'Decrescita' (Italy, 2004) and 'Decreixement' and 'Decrecimiento'

[276] *Why Societies Collapse and What It Means for Us*. Joseph Tainter (2010) at the 2010 International Conference of Sustainability: Energy, Economy and Environment. Link: https://www.youtube.com/watch?v=G0R09YzyuCI
[277] Research and Degrowth is an academic association dedicated to research, awareness raising, and events organization around the topic of degrowth. Further detail can be found at: http://www.degrowth.org

(Catalonia and Spain in 2006) as social movements to promote alternatives to BAU (Demaria, Schneider, Sekulova & Martinez-Alier, 2013). This included features such as car free cities, food cooperatives, anti-advertising, “meals in the streets” along with other means to rethink a different way for humans to live, working to promote the concept of degrowth as desirable in comparison to collapse (Ott, 2012; Tammilehto, 2012; Demaria et al., 2013; Kaivo-oja et al., 2014).

Degrowth is the literal translation of its French origin décroissance and can be defined as a collective and deliberative process with the desired goal to equitably reduce societal capacity of production and consumption to better fit the needs of ecological and social sustainability (Demaria et al., 2013; Sekulova et al., 2013). Degrowth is not an economic concept and is argued to be more of a “multidimensional concept” containing within it diverse roots such as anthropology and anti-utilitarianism (Demaria et al., 2013). Garcia (2012) points out that degrowth has emerged from the perception that the natural limits to growth have been exceeded and the industrial civilization has reached a point of overshoot. Through a prolonged economic and demographic descent, a plateau of sustainability will be reached where either the industrial civilization creates a planned and controlled degrowth or nature will dictate one that is unplanned and chaotic (Garcia, 2012; Murray & King, 2012).

Ontologically, degrowth challenges growth, even the BAU variants of green growth, green economy, desirability of economic growth and economics core principles of neoclassical economics and Keynesian economics (Demaria et al., 2013). The degrowth narrative therefore emerges as a mitigative and adaptive response to a growing crisis of physical, ecological, social and economic limits. Mitigative measures that reduce energy consumption would be reduction in the number of electrical appliances, using simpler repairable technologies, consumption reduction basically reducing the level of complexity in global civilizations. Adaptive measures point to reduced consumption through smaller, simpler, livable walkable communities, replacing the car dependent high transport energy community needs. Consumption becomes more geared towards the needs of sustenance, controlling and regulating advertising and reducing the need to continue to growth profit through creating increased numbers of community and social non-profit enterprises (Sekulova et al., 2013).

Degrowth clashes head on with growth, the normative mantra of neoliberalism, economic, government and industrial policy which leaves the concept of degrowth to not be considered seriously even though many agree with the need to challenge uncontrolled BAU growth (Levallois, 2010; Alexander, 2016)[278]. As such, degrowth could be introduced into the classroom as an idea finding ways and means to live a life exploring the needs of sufficiency and qualities of a meaningful life stepping away from the ontology of infinite growth. This results in working to create a different epistemological framing away from one dedicated to serving a need to grow the economy.

> The dominant economics in this twenty-first century of increasing ecological turmoil is a relic of nineteenth century thinking. Its intellectual founders, motivated by the remarkable success of Newtonian physics, set out explicitly to model economics as the "mechanics of utility and self-interest." The discipline consequently lost sight of the social context and

[278] Alexander (2016) points out that suggestions that nations might give up economic growth or embrace a degrowth policy are "typically met" by mainstream economists with "fierce resistance". The preferred narrative of these economists is that markets can grow indefinitely though better design, market innovation and technological innovation.

purpose of economies and became totally abstracted from biological reality (Rees, 2015, pp. 3).

Energy in Economics

Georgescu-Roegen's The Entropy Law and the Economic Process (1971), published a few months prior to Meadows et al., (1972) Limits to Growth, "both questioned the assumption made by nearly all currents in economics that the expansion of GDP was the ultimate goal of economic policy"[279] (Levallois, 2010, pp. 2277). While the Limits to Growth book brought challenges of resources, environment and population growth to be placed on the United Nations Conference on the Human Environment (Stockholm, 1972), global concerns over fossil energy resources gained prominent post 1973 Arab Oil Embargo (Røpke, 2004; Kümmel et al., 2010).

Hall and Klitgaard (2012) both critique classical and neoclassical economics (the dominant discourse present in today's economic circles[280]) as lagging behind chemistry, physics and biology in that economics has yet to be transformed by the reality of thermodynamics, which means for Hall that traditional studies of economics is one of a "fairy tale". Hall illustrates this critique using a Cobb-Douglas production function where production is defined as a function of capital and labor [P = f (K, L)]. This function however, only accounts for about half of the

[279] The early alliance between Georgescu-Roegen and Meadows et al., (1972) combining strengths of economic rigor and computer-based systems dynamics to explore future economic, ecological concerns, came to an end due to the Club of Rome "*shying away from adopting a clear negative-growth slogan*", a move that Georgescu-Roegen took to be "*a lack of commitment to the decline of the economy*" (Levallois, 2010).
[280] Alan Greenspan (2013) noted both the Federal Reserve Board's and the IMF models concluded that economic global risk of collapse had decreased since September 2006 and that J.P. Morgan was predicting an acceleration of growth in the U.S. economy all prior the 2008 financial collapse.

production and the remainder, termed residual production is considered the byproduct of innovation, rather than energy which when added to the production function accounts for nearly all the residual (Hall, Lindenberger, Kümmel, Kroeger & Eichhorn, 2001). Energy has been found by Hall et al., (2001) to be a better predictor of production than capital and labor outlaid in the traditional Cobbs-Douglas function. Barnett et al., 1963, famous analysis over increasing scarcity of natural resources from 1870 to 1957 discovered that inflation adjusted production costs had either fallen or remained constant for agricultural goods and minerals with the exclusion of forestry products (Cleveland & Stern, 1998; Tanhoven, 2000). However, Cleveland and Stern, (1998) in reanalyzing the same resource productions costs found they only remain low due to increased energy use and only if energy prices remained low.

The removal of energy as a primary driver of economies[281] was one that transitioned away from the earliest economic school (Physiocrats) which considered wealth to be a byproduct of land (sometimes including natural resources and raw materials) and labor. This evolved into the general idea that labor was the source of wealth (Adam Smith, Karl Marx) in classical economic studies that later focused on the importance and role of markets in neoclassical economics (Hall & Klitgaard, 2012). In 1956, Robert Solow in a paper that has since been cited nearly 20,000 times, advanced neoclassical economics further through his removal of labor and leaving capital as the sole function in the production of wealth[282].

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[281] Prior to the introduction of coal into the economy in the mid 1700s, energy was limited to wind, water, wood, human and animal. Since Hall and Klitgaard's (2012) model only illustrates energy decent, one should question what a stabilized post-fossil energy economy might look like.
[282] Ayres, Van den Bergh, Lindenberger and Warr (2013) Challenge the standard economic theory where capital and labour satisfy the "cost-share theorem" as being main factors of production. They argue energy, is a greater factor of production than indicated by its small cost share. They see this as a risk to continued historical global economic growth "in view of

Herrmann-Pillath (2015) in his ontological revision of economics argues for the need to create two new economic tenets: First the market cannot be understood as an institutional instrument to work around energy constraints using increased efficiency and technological improvement and it is a fatal misconception to believe that markets can escape the laws of thermodynamics. Technology is not a substitute for energy, meaning that "if neither markets nor technology are means to resolve the environmental challenges of today, those positions in ecological economics are vindicated which argue that fundamental changes of the values and institutions of capitalism are necessary to establish a sustainable global economic system" (pp. 434).[283] Growing numbers of economists and scientists increasingly challenge both the relevancy and accuracy of neoclassical economics by questioning if "modern economic theory is based upon a flawed interpretation of the world[284], in its relegation of energy and labor to that of a minor footnote in its foundation of creating economic growth?" (see Figure 6.2). Addressing this limitation, ecological economics has rapidly grown becoming institutionalized with the formation of the International Society for Ecological Economics (ISEE) (1988) and quickly followed by the inaugural issue of Ecological Economics in 1990 (Røpke, 2004; 2005). From the onset, ecological economics was heavily influenced by an awareness of thermodynamics and nature,

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considerably higher energy prices in the future due to peak oil and climate policy" (Ayres et al., 2013).

[283] Seventeenth and eighteenth century societies were characterized by small populations, low productivity and it can be readily understood that political economy would be centered on increasing production through increased labor productivity, population growth and by shaping the social institution of capitalism (Foley, 2012).

[284] Wassily Leontief (awarded the Nobel Memorial Prize in Economics, 1973) expressed his concerns in 1982 letter in Science: "Year after year economic theorists continue to produce scores of mathematical models and to explore in great detail their formal properties; and the econometricians fit algebraic functions of all possible shapes to essentially the same set of data without being able to advance, in any perceptible way, a systematic understanding of the structure and the operations of a real economic system" (pp. 104).

and was composed of several disciplinary roots: systems, biophysical, environmental, resource, agricultural economics and socio-economics (Røpke, 2005; Georgescu-Roegen, 2014). Central to biophysical, environmental and resource economics are the capacity of ecosystems to absorb pollution, the resources available for production and the utilitarian value of the enjoyment of nature (Røpke, 2004).

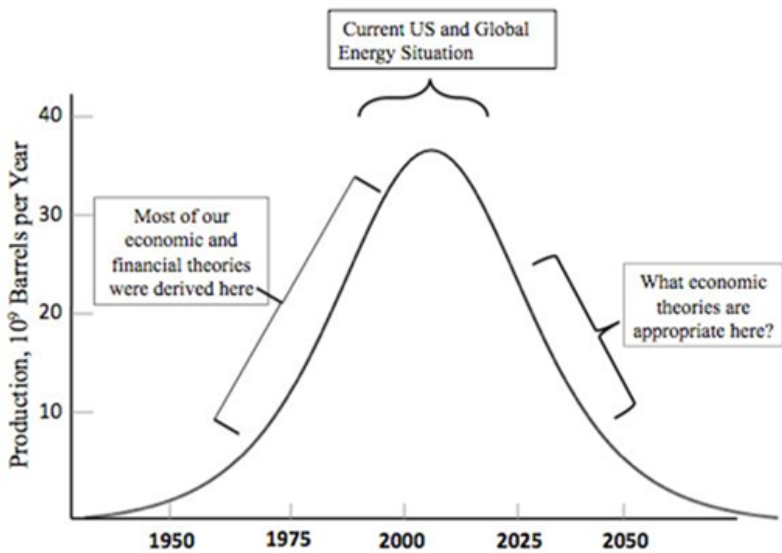

Figure 6.2 Visual comparison between the rise and fall of conventional fossil fuel consumption and economic theory (Source: Hall & Klitgaard, 2012)

The promise of ecological economic variants due to their inclusion of thermodynamic laws holds promise that economic theories will begin to account for the role of net energy within the economy. Whether alternate economic variants might come to dominance in time to influence human consumptive behavior is debatable, it can be argued that they hold out great promise in understanding and presenting an accurate model to understand current and future economic conditions. In surveying, ecological economics readings there appear a common theme that fossil fuel usage will diminish and turn into a secondary fuel supporting the increasing development of renewable primary energy sources. From this thought, one should expect a rapid decarbonization of energy sources but not their elimination. Economic growth through increased consumption of energy driven by the need for economic growth, increasing global population in both workers and consumers and in increasing global debt cannot be expected to be sustained in a world of diminishing returns and increasing externalized cost to humanity and the ecosystem (Ayres & Warr, 2005).

Energy descent for classical and neoclassical economics could be the watershed event pushing normative economic theory into the realm of post-normality since the founding assumptions and paradigms of these models would be found to be incomplete. Classical, neoclassical projections and predictions of economic behavior should continue to become more unreliable for their underplaying of energetic inputs. Thus, in using current economic understanding, there is serious risk that government, corporate, financial and other agencies increasingly disconnect themselves from the real economy and that their projections[285] will fail to recognize global trends[286] that are increasingly aligning themselves with the earlier Meadows et al., (1972) LTG BAU scenario. Considering this, one should address what corporate and political actors are doing to maintain BAU economic growth and energy consumption?

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[285] Many analysts had expected the 2014-2015 drop in oil price would have resulted in significant economic stimulus since energy goods and services as a percentage of total consumer spending dropped. However, the collapse in global fossil energy prices from 5.4% to 3.7% of total consumer spending did not create the projected increase in consumer spending, rather spending has tracked as if there was no decease in energy cost. Interpreting these results led Hamilton (2016) to reflect that while a sharp increase in fossil energy prices would reduce the U.S. GDP, a decrease in does not imply the reverse.

[286] BP Energy Outlook (2016) is projecting growth to return to its historical 3.5%, doubling global GDP by 2035, while reducing energy consumption by 2.1% annually, which means that that overall energy consumption will increase by 1/3. Carbon emissions will continue to rise at an annual rate of 0.9% rather than the last decade of 2.1%.

Obstructions to Changing Fossil Energy Consumption

The fossil energy economy is massive where 90 corporations involved in oil, natural gas, coal and cement account for near two thirds of all the global GHG emitted from 1854 to 2010 (Heede, 2013). To illustrate the financial power of just these oil companies, January 1st, 2015, the CIA World Factbook stated that global proved oil reserves were 1.656 trillion barrels which at peak in 2014 valued using the $103.63/bbl price for West Texas Intermediate (WTI) represented around $172 trillion USD and represented 2.2 times the estimated the Gross World Product (GWP) $78.3 trillion USD for the same year. At the same time looking at the value of these proven reserves from peak in 2014 at $103.63 for WTI to $29.45 on January 14th, 2016, represented a global loss exceeding $123 trillion[287] for just oil and not counting other fossil fuels such as coal[288] and gas.

Corporate Sourced Climate Science Obstructionism

Recent revelations in the fossil industry prior awareness of climate impacts from fossil energy consumption has led to a multi-state lawsuit[289]. Exxon began their research in 1978 into the impact of CO_2 emissions that held potential to impact its industry, research that was duplicated by Chevron, Amoco, Phillips, Shell, Sunoco and Sohio (Banerjee et al., 2015). In 1989 the American Petroleum Institute (API), Exxon along with other major users and producers of fossil fuels created the Global Climate Coalition (GCC) a lobbying group with the mandate to "derail

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[287] There exist a range in the way oil is globally priced, with WTI, Brent and Opec references the most prevalent.
[288] On April 6th, 2016, the world's largest private coal company, U.S. Peabody Energy was driven into bankruptcy due to collapsing coal prices and crashing demand, losing 12.6% of its value the day after COP21 was agreed to (Lewis, 2016).
[289] http://www.nytimes.com/2015/11/06/science/exxon-mobil-under-investigation-in-new-york-over-climate-statements.html?_r=0.

international efforts to curb heat-trapping emissions" with COP3 and the 1997 Kyoto Accord as one of its first focused targets who President G.W. Bush credits in part for his rejection of Kyoto (US Department of State, 2001, June 21; Rahm, 2009; Mulvey, 2015). In the two decades marking 1993-2013 corporate funding supported texts working to polarize climate change understanding and to influence thematic content (Farrell, 2016). Prevalent in their assault of climate science were found positive correlations to four thematic groupings (see Figure 6.3), first challenging the scientific evidence[290, 291] over the "real causes and effects" of CO_2, long-term temperature cycles, cooling[292], and questioning who has scientific authority[293]". Secondly attacks

[290] Orekes (2015) has tracked historical evidence of the corporate climate obstructionist strategy of using scientific uncertainty as a means to create doubt, even in instances where science is in near unanimous agreement. The history of corporate influence has been traced back nearly a century to influence public policy on electrical energy generation, the links between tobacco, asbestos and cancer, lead in paint and fossil fuels with the more recent climate obstructionism.

[291] Andregg et al., (2010) in analysis of 1372 climate researchers found there to be a 97-98% agreement with the IPCC primary conclusion that anthropogenic greenhouse gases have been responsible for most of the observed warming averaged over the planet. Benestad et al., (2015) in analyzing the publications of the researchers rejecting AGW discovered that multiple flaws from insufficient model evaluation, false dichotomies, incomplete or misconceived physics and inappropriate statistical methods.

[292] "I can tell you, our grandchildren will laugh at those who predicted global warming. We'll be in global cooling by then, if the Lord hasn't returned. I don't believe a moment of it. The whole thing is created to destroy America's free enterprise system and our economic stability." (Reverend Jerry Falwell, 2002, November 20).

[293] On January 17, 2014, Copernicus Productions an open-access Göttingen publisher in Germany terminated the journal "Pattern Recognition in Physics" less than a year after inauguration after it was found to contain significant amounts of self-plagiarism in articles authored by climate skeptics and editor-in-chief Sid-Ali Ouadfeul, an Algerian Petroleum Institute employee. Martin Rasmussen (managing director of Copernicus Productions), writing on the Pattern Recognition in Physics website stated that the journal was cancelled following concerns over evidence that "the editors selected the referees on a nepotistic basis, which we regard as malpractice in scientific publishing and not in accordance with our publication ethics" and from a December issue where "special issue editors ultimately submitted their conclusions in which they "doubt the continued, even accelerated, warming as claimed by the IPCC project" (Pattern Recogn. Phys., 1, 205–206, 2013)" (Rasmussen, 2014).

focused on sources of public knowledge, targeting Al Gore, and news media[294]. Third, attacks were focused upon federal and state bureaucratic politics related to climate change and a fourth group focused on energy industry concerns working to create alarm over the economic and political costs of acting on climate change policy.

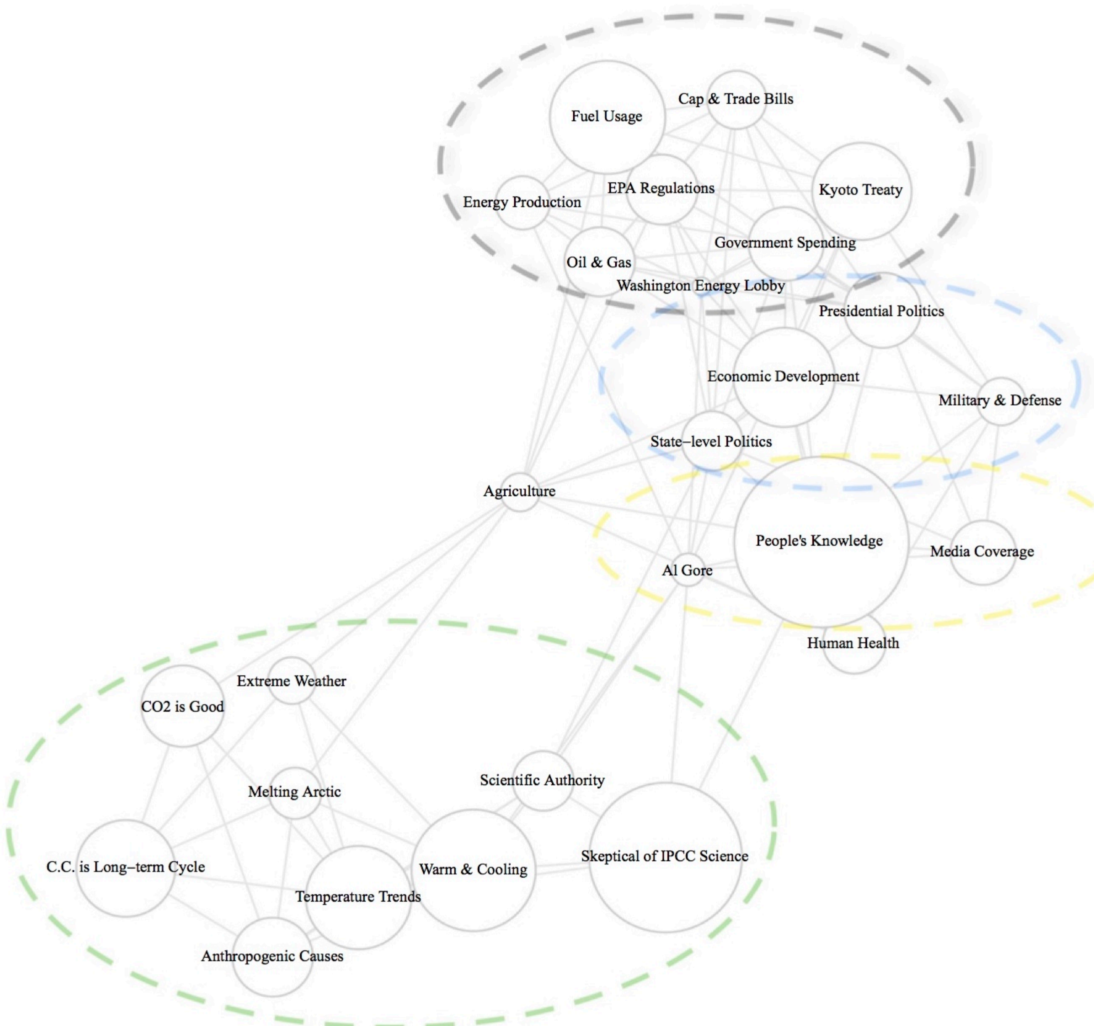

Figure 6.3 Global Climate Coalition’s thematic grouping of four designated targets to discredit (Source: Farrell, 2016)

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294 Research shows that conservative media works to increase scientific mistrust and non-conservative media increase scientific trust (Hmielowski, Feldman, Myers, Leiserowitz & Maibach, 2013).

Brulle (2013), in investigating the sources funding climate obstructionist campaigns (see Figure 6.4) uncovered $558 million USD for the period 2003-2010[295] where dominant funders also promoted “ultra-free-market ideas”. In the later years of data collection, Brulle found evidence indicating that the Koch Brothers[296] and ExxonMobil had moved to hide their contributions

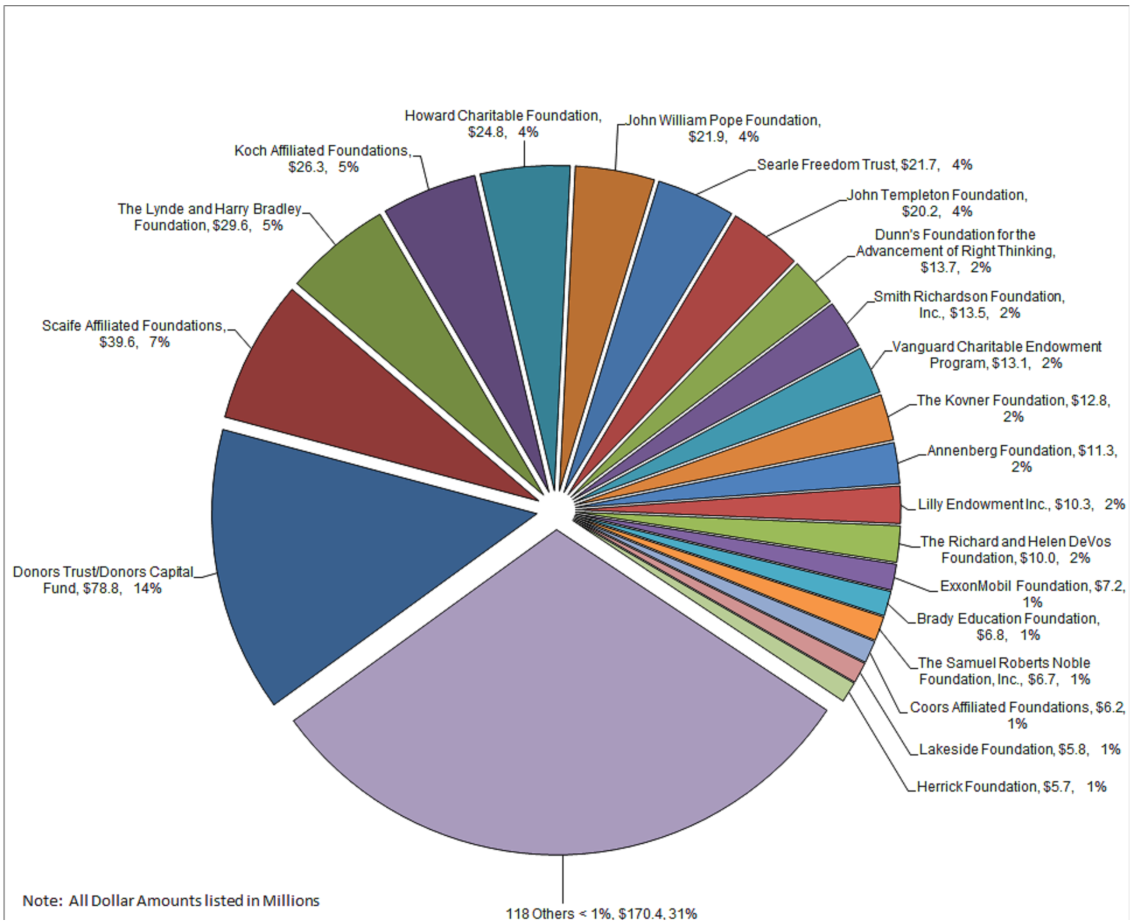

Figure 6.4 Total foundation funding given to various U.S. climate obstructionist organizations during the years 2003 to 2010 (Source: Brulle, 2013)

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[295] In 2015, InfluenceMap.org calculated that fossil industry funding from just five organizations to climate obstructionist organizations to total $123 million USD: American Petroleum Institute (API) ($65 million), ExxonMobil ($27 million), Shell ($22 million), Australian Petroleum Production and Exploration Association (APPEA) and the Western States Petroleum Association (WSPA), ($9 million). Link to all reports: http://influencemap.org/reports/Reports

[296] The International Forum on Globalization (2013) estimates that the Koch Brothers stand to profit in excess of $100 billion USD from the approval of the Keystone XL pipeline (International Forum on Globalization, 2013).

through an organization called the Donors Trust[297]. Collomb (2014) in his research exploring the differing climate change obstructionism in the U.S. compared to Europe, has identified the change in strategy away from denying climate change is occurring to one that focuses on adapting to climate change and protecting the American way of life. Further, Collomb (2014) has gathered evidence in what he terms "the last refuge" of the climate obstructionist is in the promotion that negative externalized costs of climate change are "grossly overstated" and that acting to mitigate increasing the negative effects of climate change is far more costly than beneficial and even then, for insignificant results. The Heartland Institute, one of the more prominent of the climate obstructionist organizations has since 2013, focused their attacks on the integrity of academic scientists, perhaps piggybacking on the level of scientist mistrust after the climategate email hack of East Anglia University in 2009 (Leiserowitz et al., 2013; Bromley-Trujillo et al, 2015; Cann, 2105).

This has resulted in increasing pushback by climate scientists compiling evidence from peer reviewed research indicating there exist near complete consensus in scientific interpretation that human sourced carbon emissions are a major contributor to global climate disruption (Cook, et al., 2013; Curry & Webster, 2011; Cook, et al., 2016; Lewandowsky, Mann, Brown & Friedman, 2016). Lewandowsky et al., (2016) note the level of the attacks against scientists have crossed into the nonsensical using claims by James Inhofe in that climate science is a "hoax" perpetrated by "corrupt scientists" and of the billboard campaign comparing climate scientists to the Unabomber to illustrate this (see Figure 6.5).

[297] The "Donors Trust is just the tip of a very big iceberg" (Brulle, 2013).

Figure 6.5 Heartland Unabomber Billboard. (Source: Heartland.org)

Corporate Influenced Politics

Lobbying, campaign spending, regulatory commissions and panels, astroturf groups and media complicity all highlight methods used by the fossil fuel industry to influence politics in the United States[298]. Chen et al., (2010, 2015) argue the most important of these are in the larger lobbying efforts (one or two orders of magnitude larger than PAC spending) and the lesser monetary donations to politicians, political parties and organizations (see Figure 6.6). In a data set comprising "3,209 firm-year observations" a positive correlation was found between lobbying expenditures and market valuation, investment return, account earnings and cash flow from operations (Chen et al., 2010). For fossil fuel industries, Oil Change International (2016) estimates that a little over $350 million USD from oil, gas and coal interests was expended on

[298] Further detail can be found at: http://www.eastbayexpress.com/SevenDays/archives/2015/07/29/californias-biggest-secret-oil-industry-capture-of-the-regulatory-apparatus

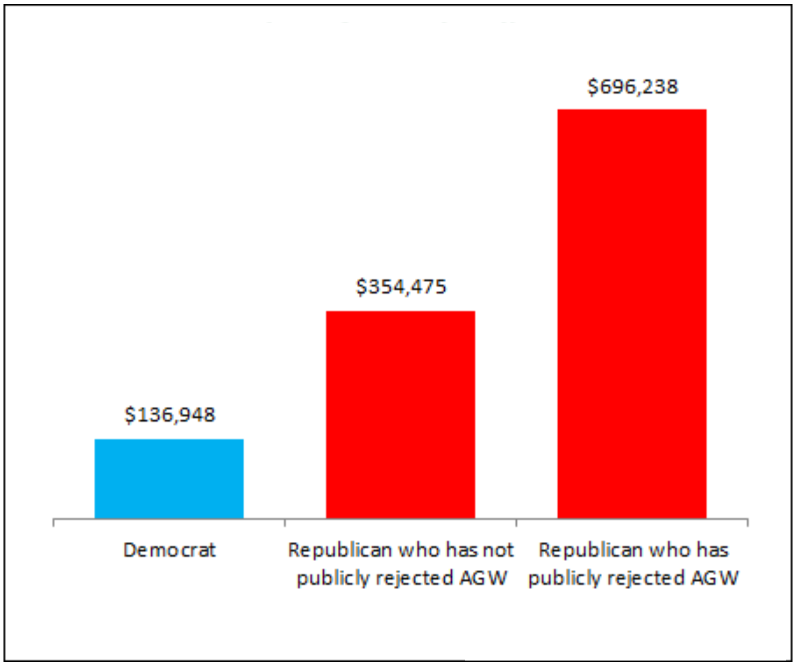

Figure 6.6 Average donations from fossil fuel industries to U.S. Senators (Source: politicsthatwork.com, 2016)

politicians which they compared to the estimated $41.8 billion returned to fossil fuel industries in the form of "federal production and exploration subsidies". Globally, Gupta, Dhillon & Yates, (2015) points out that in 2010, close to half a trillion dollars USD was spent on fossil fuel subsidies with the intention of protecting the poor from high cost fossil fuels has resulted in the overconsumption of fuel, reducing efficient usage that benefit in most part wealthier households. From the perspective of Gupta et al., (2015) this subsidy would have been better used to mitigate future climate change through fossil fuel reduction and in working to reduce health and income inequalities.

The U.S. Republican Party (GOP) in gaining increasing power since President G.W. Bush have increasingly worked to obstruct climate research, moving money away from NASA's Earth Science program budget, dictating that NASA should be more focused on "blasting into and exploring space"[299]. The National Academy of Sciences (2012) in a report outlining the risks to Republican funding cuts to the Earth Science program indicated that as of 2005, a system of environmental satellites was at risk of collapse and that several cancelled and delayed missions have worked to hinder much needed research. On April 2016, the National Snow and Ice Data Center (NSIDC) was forced to suspend the use of data from the Defense Meteorological Satellite Program (DMSP) F-17 due to the failure of a crucial satellite sensor where the replacement satellite F-20 sat on the ground in storage (Harvey, 2016; NSIDC, 2016).

Climate science is not the sole target of the GOP, as evidenced in their 2015 House Budget. In this budget under the guise of energy independence within 10 years, they set out policies to encourage oil and gas exploration onshore, offshore, public and on private lands. Further, the budget rescinded all un-obligated green stimulus programs[300] and promised to restrict the government from acting in the energy market. Further, the Republican party indicated that they will work on "streamlining or outright repealing inefficient, ineffective or counter-productive regulations like those perpetrated under Dodd-Frank or conjured up in the halls of agencies like the Environmental Protection Agency (House Budget Committee (2015) pp. 11)". Foran (2015) adds that the Republican party rejects any carbon tax and calls for the U.S. Department of Defense and the Central Intelligence Agency to cease their study of climate change. Goodstein (2013) points out the Republican party back in 2012 had clearly targeted government support of

[299] Further detail can be found at: http://www.theatlantic.com/politics/archive/2015/05/republicans-nasa-wastes-money-on-climate-change-research/452505/

[300] Goodstein (2013) Mitt Romney during the 2012 U.S. Presidential election abandoned his former support for alternate, green energy sources and worked to oppose the continuation of U.S. tax credits, a federal policy that had been in place for over 20 years to support and grow a fledgling industry.

wind and solar generating programs with what he stated was a complete surrender to the Tea Party climate denying activists and billionaire funders with connections to the major oil and gas companies who profited more than a trillion dollars USD in the previous decade. Lewandowsky et al., (2013) separates conservative voters away from the free-market worldview members (most likely to reject climate science) and those invested in conspiracist ideation (likely to reject all science). There have been recent movements within the Republican party to step back from its dominating climate obstructionist stance. This movement with founders Carlos Curbelo (Florida Republican Congressman) and Ted Deutch (Florida Democratic Representative) created the first bipartisan "Climate Solutions Caucus" on February 1, 2014 in direct response to growing concerns of sea-level rise in South Florida, in particular the billions of assets threatened in Miami. This resulted in the Republican resolution presented in the 114th congress, 1st session expressing a commitment to conservative environmental stewardship, however it must be pointed out that there are challenges remaining to be reformed[301].

In 2006, then Canadian prime minister Stephen Harper began a crackdown on government scientists in his prioritization of boosting economic growth mainly through resource extraction to stimulate development (Hoag, 2012; Ogden, 2016). Through Harper's nine-year term in office he removed numerous environmental regulations, blocked journalists from contacting government scientists to ask about environmental or climate change issues, sent government "media minders" to shadow scientists at conferences and employed delaying tactics that prevented journalists from making deadlines. In attempts to interview Canadian scientists, Ian Stirling compared the control

[301] "With all of the hysteria, all of the fear, all of the phony science, could it be that man-made global warming is the greatest hoax ever perpetrated on the American people? It sure sounds like it." James Inhofe, 2003 speech in U.S. Senate.

of the Harper government to that of the 1970s Soviet Union but less restrictive than a former journalist felt what was imposed in China (Ogden, 2016). Ogden (2016) further goes on to describe the Harper political influence to be “untenable for scientists” through his muzzling and censoring of scientists in communicating their work to the outside.

Working to find common ground between changes in fossil fuel products and costs of production, increasing externalized costs due to consumption and the economics invested in continuing and growing usage of fossil fuels all combine to define a truly wicked problem. Corporate and political leadership cover all spectrums with actors invested in maintaining or growing BAU to the extent they might be considered malfeasant in their behavior. Changing consumptive behavior remains paramount but with competing interests challenging, resisting and obstructing change, one can expect that students will be exposed to conflicted ontologies. The question remains, “what should I reframe in my teaching to prepare students for the emerging world?”

Chapter Seven

Conclusions and Implications

> Sustainability outcomes may take decades or centuries to develop. Historical studies reveal three outcomes to long-term change in problem solving institutions: collapse, resiliency through simplification, or continuity based on growing complexity and increasing energy subsidies (Tainter, 2006, pp. 91).

This dissertation emerged from a single question which resulted in a work that argues that humanity needs to understand fossil energy consumption from a different ontological framing than one of continued support or acceptance of industrial civilization's BAU growth and consumption and likely requires ontological reframing to redefine one's epistemological understanding (Orr, 2004; M'Gonigle & Strake, 2006; Miller, 2007; Kahn, 2010; Raddon, 2010). In creating this ontological reframing, it becomes necessary for educators to challenge the evolved post World War II curricula promoting growth focused consumption and supporting associated pedagogies (Orr, 2004; Welsh, 2007; Giroux, 2010; Sandlin and McLaren, 2010). This requires that one critically explores fossil energy consumption, engaging in an autodidactic process and understand the systemic relations and factors leading into a fossil energy descent (Hostetler, 2005).

This dissertation is a comprehensive narrative resulting from the search of computerized databases, interest groups, conference proceedings, authoritative texts and blogs covering the complexity of a fossil fueled world in transition (Green, Johnson and Adams, 2006). Most of the writing here soon will be dated and for this work to remain accurate, it will require constant updating, expansion and or retraction as relevant new data emerges. The exciting part of surveying fossil energy and related research resources comes from the ontological re-evaluation of both the past and current events while observing and understanding the possible futures that unfold. Some projections and predictions are terrifying yet others are exciting since the industrial civilization is now being challenged to create a new future, finding ways to sustain what is valuable and worth retaining while working to discard and abandon the unneeded. In working to address and understand what a post fossil energy world could look like, there are numbers of transdisciplinary questions that need to be investigated by educators centering around LTG stabilization, BAU challenges, restructuring capitalism, challenging consumption, the implications of EROIE and Net Energy and the impact of climate disruption.

Conclusions to Research Questions

Question One: What is the evidence that industrial civilization faces a future of conventional fossil energy descent?

Oil, natural gas and coal were all expected to outstrip supply within the next decade prior to recent global disruptions, collapsing demand and rise in unconventional fossil fuels. In working to better understand coming changes and challenges in the supply and demand of fossil fuels it is valuable to recognize that globally, fossil energy supply and decline is most complicated.

Specific Conclusions

Data continues to show that models of depletion and growth limitations proposed from theoretical, mathematical and physical models are closely tracking the BAU trajectory outlined in the limits to growth model (Hall & Day, 2009; Tainter, 2010; Bardi, 2011; Randers, 2012;

Turner, 2014, 2015). Data also show that production of all conventional fossil sources of energy have peaked or are projected to be in the process of peaking by 2025 (Ingles & Denniss, 2010; Owen, Inderwildi, & King, 2010; Maggio & Cacciola, 2012; Sorrell, Speirs, Bentley, Miller & Thompson, 2012; Chapman, 2014; Bentley & Bentley, 2015; Warrilow, 2015).

For conventional oil, production has plateaued, with evidence of it having plateaued from 2004 to peak in 2011 before heading into permanent decline (Hirsch et al., 2010; Staniford, 2010; Shell Oil, 2011; Hallock et al., 2014; Berman, 2015). Global proved reserves of conventional oil are overestimated and perhaps closer to 875 billion barrels instead of a stated 1.7 trillion barrels Jefferson (2016) with projected conventional oil shortages, representing a shortfall of over 60 MMbpd by 2031. This represents the equivalent to conventional oil from six Saudi Arabia, meaning a new Saudi Arabia needs to be discovered and developed every 3 years, 4 months for the next twenty years (IEA, 2008). Fracking as a source of unconventional gas and oil production promoted as a game changer for energy independence is increasingly contested due to multiple concerns including earthquakes, methane escape, wasteful flaring, excessive water use, soils & water contamination, radioactive waste and regional health impacts (Ellsworth, 2013; Sovacool, 2014a; Hildenbrand et al., 2015; Casey et al., 2016; Hildenbrand et al., 2016; Lauer, Harkness & Vengosh, 2016; Petersen et al., 2016).

For other fossil fuels, the peak energy attained from coal is projected to occur between 2011 (Heinberg, 2009a; Patzek & Croft, 2010) and 2025 (Mohr, Wang, Ellem, Ward & Giurco, 2015) with post peak expected declines to range between 2% to 4%. Uranium as a source of fuel is expected to peak in 2015 (Dittmar, 2011a) and should meet with supply problems by 2020, where after it is expected that "severe uranium supply shortages" will stall any extension of nuclear power (Zittel, Schindler & Bölkow, 2006). Nuclear power is not scalable to replace all energy produced from fossil energy since expanding nuclear power to replace all fossil sourced power would require an increase from the 435 power plants operating (as of 2008), to 10,730 power plants, which would rapidly burn all RAR uranium resources in a little over 5 years (Dittmar, 2011a, EIA, 2012).

The most profitable resources and ones most accessible with the highest EROI and Net Energy were probably drilled and exploited first leaving industrial civilization with the less profitable resources to extract with declining EROI and Net Energy benefits to civilization (Holditch, 2006; Brierley, 2007; Murphy & Hall, 2011a; The Hills Group, 2016; Tverberg, 2016). As capital expenditure or capital expense (CAPEX) costs for drilling, exploration, production and lease payments continue to rise, along with rising debt, there is an increasing risk of production collapse of unconventional sources that have the fastest depletion rates and highest costs of production (EIA, 2010; Weijermars, 2011; Arezki & Blanchard, 2014; Rook & Caldecott, 2015; Deloitte Center for Energy Solutions, 2016; Stevens, 2016; Underhill, 2016).

Implications for Theory, Future Research and Debate

Whereas capitalist economics currently dominate decisions about the energy production from the perspective of a profit framework, it should be strongly argued EROI and Net Energy are what define the ultimate value of energy to civilization (Hall et al., 2009; Murphy et al., 2011; Murphy & Hall, 2011a, 2011b). Despite the benefits of using EROI and Net Energy metrics, one problem that continues to plague their utility stems from defining the boundaries of energy expended in production. This lack of a convention to define these boundaries result in significant variability in the EROI and Net Energy outcomes for the same finished product (Mulder & Hagens, 2008; Murphy, Hall & Powers, 2011; Tello et al., 2015). Also, the lack of a universal, common or standard definition for the different ways the oil and gas industry classify unrecovered oil and gas, work to create polarized views that hinder understanding current and projected measures of exploitable reserves (De Castro, Miguel & Mediavilla, 2009; Owen et al., 2010; EIA, 2013; Murray & Hansen, 2013; Chew, 2014).

Research is needed to address what EROIE is needed to maintain various aspects of civilization and what is needed to maintain our current industrial society beyond the original works of Hall et al., (2009), Hall et al., (2014) and Lambert et al., (2014). Ongoing research into EROIE, net energy and growing negative externalities defining energetic challenges confronting industrial civilization's must aggressively investigate economies, transportation, food production and lifestyles heavily dependent on cheap, abundant, high quality fossil energy, disruptions, rapid changes and declining net energy (Murphy and Hall, 2011a, 2011b; Hallock et al., 2014; The Hills Group, 2016). Research must also be done to identify expected changes to energy consumption and how these would this impact lifestyles and economies.

Question Two: What is the evidence of the growing uneconomic costs associated with fossil energy consumption?

Uneconomic costs or negative externalities defined as the social cost of carbon are predominately recognized from actual and projected climate disruptions. Humanity emerging from the Holocene into Anthropocene now faces growing challenges due to global disruption to climate and seasonal weather patterns, through increased violence of storms, the growing intensity of droughts or rain and in the relentless rise of heat and sea level. The evidence of uneconomic costs resulting from climate change are overwhelming with many of these summarized in the specific conclusions listed below.

Specific Conclusions

The physics and chemistry at the foundation of climate science has been known for over two centuries. CO_2 atmospheric emissions place atmospheric concentration at a level last seen at the start of the Pleistocene, 2.6 million years ago and if continued at projected BAU levels will reach conditions last seen in the Cenozoic (Weitzman, 2015; Crucifix, 2016). Fossil fuel combustion and industrial processes amounted to 78% of the total greenhouse gas emissions between 1970 and 2010 (IPCC, 2013a).

BAU fossil consumption ensures the world of the future is one of increased desertification and flooding (Stocker et al., 2014; World Bank, 2014; Guiot & Cramer, 2016; Norris et al., 2016). Food security will suffer as expected yields are expected to encounter rapidly increasing and significant impacts after the average global temperature climbs 1.5-2°C (World Bank, 2014).

"A world in which warming reaches 4°C above preindustrial levels, would be one of unprecedented heat waves, severe drought, and major floods in many regions, with serious impacts on human systems, ecosystems, and associated services" (World Bank, 2012, pp. 13). BAU projected precipitation levels can be characterized as a massive disruption to current rainfall patterns due to the climate movement from mid-latitudes towards the poles from a phenomenon termed Hadley Cell expansion (Dyer, 2009; Norris et al., 2016).

"Climate change risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. Increasing magnitudes of warming increase the likelihood of severe, pervasive and irreversible impacts for people, species and ecosystems" (IPCC, 2014, pp. 64). For a 2°C increase in temperature, tropical human populations and ecosystems would be required to migrate distances greater than 1000 km to survive, increasing some populations densities 300% or more, with roughly 1/8 of global population traveling 1000 km and 1/3 migrating more than 500 km (Hsiang and Sobel, 2016). For a 2°C increase in temperature, ecosystem migration would need to migrate an average of 11-22 km/y to survive (Hsiang and Sobel, 2016).

Significant numbers of small island states have been recognized by the UN, UNFCCC and IPCC as being among the most vulnerable of countries facing sea level rise and projected extreme weather events. Over 150 million humans live on areas one metre above high tide and 250 million within five metres, meaning hundreds of millions will be affected in any scenario due to rising sea levels and salt water intrusion into fresh water sources and onto food producing lands (Lichter, Vafeidis, Nicholls & Kaiser, 2011; UNEP, 2014; Hoad, 2015). Projected numbers of climate refugees in 2050 range from 50-200 million (Gemenne, 2011) and increases to hundreds of millions by 2100 under the BAU scenario (IPCC, 2013a).

Implications for Theory, Future Research and Debate

Paleoclimatic evidence of the violence of Eemian storms have been found in the Caribbean to have deposited debris 20 to 40 m above sea level and kilometres inland. Should the violence of Eemian storms reappear in the next couple of centuries, one might expect extensive destruction of large inhabited areas near sea level and loss of all coastal cities (Hearty & Olson, 2011; Hansen et al., 2016). Also of concern is evidence from the Eemian period approximately 130,000 to 115,000 years ago that points to a sea level rise 5 to 9 m above present, with pre-industrial atmospheric CO_2 levels of 270 ppm (Luthi et al., 2008; Hansen et al., 2016). Paleoclimatic research needs to be aggressively pursued since current research has uncovered concerning evidence of the violence of the climate disruptions that occurred with CO_2 concentrations around 135 ppm less than is in the current atmosphere. One of these for example is that sea ice melt above a certain amount can shut down ocean circulation, (SMOC and AMOC) which could be expected to result in catastrophic anthropogenic climate forcing rates in regions by as much as 50 W/m^2 (Hansen et al., 2016).

IPCC and COP are the global centerpiece of international cooperation acting to reduce the negative externalities mainly resulting from fossil fuel emissions and both have serious challenges that need to be addressed. Specifically, they are: (1) IPCC is one of science's most conservative climate science organization and because of this, statements continue to underestimate the severity of expected climate change (Brysse, Oreskes, O'Reilly &

Oppenheimer, 2013; Wigley and Santer, 2013; Dyer and Davis, 2015; Howard & Sylvan, 2015; Mann, 2015). (2) IPCC synthesis reports are out of date when published (Spratt, 2007; Dyer, 2009; Björk and Solomon, 2013). (3) The Summary for Policymakers of the IPCC AR5 WG1 is a compromise between what is scientifically necessary and what is deemed to be politically and economically feasible. It is a document of appeasement and should be rejected as being not suitable for policy creation (Wasdell, 2014, pp. 21). (4) COP 21 pledges termed Intended Nationally Determined Contributions (INDCs) when tabulated show that intended pledges are currently enough to reduce expected warming to 3.6°C by 2100 and represent 36% of needed changes to stabilize at 2°C away from the projected BAU scenario (Climate Policy Observer, 2016). (5) The "flexible framework" of INDC's post COP21 is too weak to keep warming below even the 2°C target (Rogelj et al., 2016). (6) The planned shift away from positive to negative emissions requires burning biomass and capturing emissions but research is much further behind for this than expected (McSweeny & Pidcock, 2015).

Greater investigation into projected resource limits should occur by updating the LTG WORLD3 model to include climate change impacts (Meadows et al., 2004; Rockström et al., 2009; Turner 2014, 2015). Some of the more prominent climate challenges needing continued investigation is in the water shortages, temperature and sea level rise that combine to affect food and water security, population migration, ecosystem extinction, energy demand and production along with threatened coastal infrastructure and low elevation places of habitat (National Academies of Sciences, Engineering & Medicine (NAS), 2016).

Question Three: What are the financial benefits/risks and who are the major agencies promoting the consumption of fossil energy?

It can be argued that interests preventing change and continuing to promote BAU, doing all possible to maintain unsustainable lifestyles seem to guarantee the future of industrial civilization will be one of global collapse. This is a challenge for humanity to decide: do we dedicate resources to trying to maintain industrial civilization's BAU system or should we discard unsustainable systems destined to collapse, investing instead to create a sustainable world?

Specific Conclusions

The top 90 fossil fuel corporations involved in oil, natural gas, coal and cement account for roughly two thirds of all the global GHG emissions released during the years 1854 to 2010 (Heede, 2013). In 2010, close to half a trillion dollars USD in fossil fuel subsidies within the OPEC countries of Saudi Arabia, Venezuela, Iran, Algeria, Kuwait, Egypt and Libya were spent to protect the poor from high cost fossil fuels which resulted in overconsumption and an overall reduction in fuel efficiency (Parry et al., 2014; Gupta, Dhillon & Yates, 2015). Furthermore, lobbying, campaign spending, regulatory commissions and panels, astroturf groups and media complicity all highlight methods used by the fossil fuel industry to influence politics in the United States (Chen et al., 2010, 2015). These actions positively correlate lobbying expenditures and market valuation to investment return, account earnings and cash flow from operations. Estimates are that a little over $350 million USD from oil, gas and coal interests expended on politicians returned near $41.8 billion in the form of "federal production and exploration subsidies" (Chen et al., 2010; Oil Change International, 2016).

With climate change being primarily caused by fossil energy consumption, society could be expected to recover these costs from regulation, taxes or carbon pricing from the fossil fuel companies (Hope, Gilding and Alvarez, 2015). Globally, coal is taxed far too lightly to balance the externalized costs of its consumption whereas gasoline consumption overcharged in some countries like the United Kingdom and Germany, is subsidized in countries such as Indonesia, Egypt and Nigeria (Parry, Heine, Lis, and Li, 2014; OECD, 2016).

In the analysis of future allowable carbon emissions from coal, gas and oil reserves, 33% of oil, 50% of gas and 80% of coal reserves must remain unused prior to 2050 to leave a 50% chance of remaining below 2°C (Robins, Mehta & Spedding, 2013; McGlade and Ekins, 2015). If these unburnable assets were on the books, the business share of those reserves would be recognized as being substantially overvalued leaving as much as 85% of an individual company's assets stranded (Dominguez, 2014). HSBC (2013) has noted that investors have yet to price in near $20 trillion-dollar (US) stock valuation risk from stranded assets due to the long-term nature of proposed carbon reductions in meeting a 2°C warming target. The heaviest economic loss from all unburnable fossil fuel resources is expected to be shared between Canada and Venezuela where 99% of remaining URR would be stranded (McGlade and Ekins, 2015).

Implications for Theory, Future Research and Debate

The significant economic correlation to energy consumption dictates that in a few short years' fossil energy decline will increasingly impact global economies since currently all replacement energetic sources are considerably lower in EROIE and energy density (Murphy, 2010; Dale et al., 2011). The statement, "this changes everything" is one that can apply to this future.

One economic response to declining EROI is that more fossil fuel must be produced to maintain constant net energy which results in both increased emissions and energy cost as a share of the economy. These lower EROI fuels are generally "dirtier" resulting in greater pollution which further exacerbates negative externalized costs (Hatch & Price. 2008; Linnitt, DeMelle & Pullman, 2010; Stockman, 2013; Sovacool, 2014a; Casey et al., 2016).

Research shows that as fossil energy prices rise, money is reallocated mainly from discretionary consumption that previously added to GDP (Hall, Powers & Schoenberg, 2008; Murphy & Hall, 2010; Murphy and Hall, 2011a, 2011b). Net energy analysis also indicates that all activities revolving around the use of cheap fossil fuel will end faster than its decline in production (Hall et al., 2009; Korowicz, 2011; Hall et al., 2014). Since energy consumption correlates with the exponential growth in population over the past millennia, where population growth doubled since the discovery of coal in the mid 1860s and increased fivefold since the advent of fertilizer made from natural gas in the 1950s, bears a question: what happens to human population as energy consumption diminishes or collapses? (Borlaug, 2000).

With economies, transportation, food production and lifestyles heavily dependent on cheap, abundant, high quality fossil energy, disruptions or rapid changes to this dependency should profoundly affect energy intensive consumers (Hallock et al., 2014). Any severe disruption in OPEC would immediately spike oil prices and as in previous oil spikes should plunge economies into recession, and if severe enough, global recession (Hamilton 2011; Baumeister & Hamilton 2015). Exporting countries are the most sensitive to oil price shocks and as such the ones that show significant impacts from global turmoil (Ftiti, Guesmi and Teulon, 2014). Past energy price volatility link not only spiking oil prices, but also spiking food prices which has in the past led to global food riots (Brown, 2011; Hsiang Burke & Miguel, 2013).

Researchers in the post-peak fossil era will be forced to deal with a number of challenges, from declining EROI, diminishing conventional oil, needed transition to renewable energy sources, increasing debt accumulation, declining food production, global climate disruption, aging infrastructure needing replacement, aging populations, rising sea levels, migration away from coastlines, moving cities or building seawalls, declining growth where all of this is compounded by rapidly declining cheap conventional fossil fuels (Murphy & Hall, 2011b; Capellán-Pérez, Mediavilla, de Castro, Carpintero & Miguel, 2014, 2015; Murphy, 2014). As civilization increasingly finds itself with decreasing or negative GPD falling below the rate of population growth, per-capita wealth will decrease, risking civil disruption to any nations using economic models that exacerbate inequality. If capitalism as reflected today is increasingly focused on growing wealth for a few and impoverishing the many, then the rising tide will sink most boats, and this is one scenario where global societal collapse will be difficult to avoid (Motesharrei et al., 2014).

Scientific researchers in different regions across North America face censure, legislation, aggression and interference in research approaches that challenge the BAU ontology. Thus, research must continue to demonstrate the harm in uneconomic growth and the growing seriousness of risks policies and planning that arises from a BAU ontology.

Question Four: What are options and alternatives to reduce and decouple from fossil energy consumption?

Industrial civilization is facing several crises in attempting to maintain a BAU economy where increasing demand for fossil fuel energy has necessitated increasing amounts of unconventional fuels. These fuels require substantively higher costs to produce than conventional fossil fuels and do not provide required blends of oil to produce specialized fuels such as diesel, since their API densities are either too light (shale oils) or too heavy (kerogen shale oil and bitumen SCO). Economic growth, increasingly funded by debt has borrowed financial resources from the future to pay for today with increasing negative externalized costs from fossil energy consumption and diminishing net benefit from consumption. The economic model of increased consumption is under assault from multiple factors and attempts to maintain or increase growth are running into resource, financial and environmental limits.

Specific Conclusions

All energy sources have tradeoffs: biofuels have reduced energy density, requiring larger fuel tanks due to their lesser energy density; electric cars need electricity while the main source is coal or natural gas (Brecha, 2013). Biofuels typically have low EROIs, making them a poor choice, unsuitable to be used, unless heavily subsidized through economic policies or supplemented by other fossil fuels (Basset, Kermah, Rinaldi & Scudellaro, 2010; Murphy et al., 2011; McPhail & Babcock, 2012).

Challenges rise in calculating the monetary amount of a carbon tax needed to balance social carbon costs, whether it should be based on the energy delivered, that works to reduce energy consumption or the carbon content of the fuel that would reduce carbon emissions and choice in fuels to be consumed (OECD, 2016). Also, there is disparity over who benefits and who pays from fossil energy consumption, bringing to question who bears responsibility from past and future social carbon costs, since continued fossil consumption privileges the more developed northern hemispheric nations that have better resources to adapt to change (Watson et al., 2016).

For nations having limited financial resources and large committed expenditures, the lack of diversification away from fossil fuels and collapse of fossil fuel prices have created serious economic challenges (Hutt, 2016). At world prices below $40 per barrel oil, every OPEC nation is experiencing a shortfall in revenues to balance their budget, as projected revenues fell short by $390 billion USD from expected revenues in 2015 alone.

Implications for Theory, Future Research and Debate

The importance in the need for research challenging BAU growth ontologies cannot be understated and in my opinion, the need to research the transdisciplinary post-normal future of fossil energy descent is the greatest and most important facing industrial civilization.

In the current BAU economic regime there exist massive amounts of public and private debt, which will mainly be paid back from decades of continued GDP growth (Reinhart, Reinhart & Rogoff, 2015; Alexander, 2016). In negative GDP or degrowth economies, debt repayment becomes onerous, requiring increased lengths of time needed to pay back fixed debt from diminishing financial resources (Pattillo, Poirson & Ricci, 2011). Debt should be of great concern since it can be assumed that most future resources need to be used to help build and rebuild infrastructure needed to transition away from the fossil fueled industrial world rather than be used to pay debt.

LTG stabilization of population and industrial growth requires an ontological change away from the need for growth and arguably, a rapid transition through degrowth and behavioral change, reducing energy demands, increasing energy efficiency to reach a steady state that can be sustained by various energy sources (Alexander, 2016). Ontologically, degrowth challenges growth, BAU variants of green growth, the green economy and the desirability of economic growth, all core principles of neoclassical and Keynesian economics (Demaria et al., 2013). Consumption under a degrowth narrative can shift more towards the needs of sustenance, by controlling and regulating advertising and through reducing the need for continued profit growth by creating increased numbers of community and social non-profit enterprises (Sekulova et al., 2013). Current overconsumption in developed nations impoverishes developing nations through their over-consumption of scarce resources and affordable finite fossil energy (Alexander, 2016). In addition to researching consumptive replacements and alternatives, Cohen (2013) calls upon scholars and futurists to envision what a post-consumerist lifestyle might look like.

A declining fossil energy supply will force degrowth upon the richer countries of the world whether they want it or not with their only choice being the way they handle the contraction (Douthwaite, 2012). The emerging degrowth narrative as a response to a growing crisis of physical, ecological, social and economic limits proposes mitigative measures that reduce energy consumption. These may include such measures as the number of electrical appliances, simpler repairable technologies, consumption reduction and reducing the level of complexity in global civilizations. Adaptive degrowth measures point to reduced consumption through smaller, simpler, livable walkable communities, replacing the car-dependent high transport energy community model. Degrowth will run afoul of government, business and industry plans and policies that promote GDP growth based creation of jobs that expand tax revenues and increase return on investments. Research must aggressively find options to capitalism should it fail to confront inequality as it must if it wishes to remain the prevailing model as civilization begins a process of degrowth towards sustainability (Jackson & Victor, 2015).

Energy literacy when accounting for changes in fossil sourced net energy and EROIE make it important to understand that humanity is at a peak in fossil energy and faces a future of rapid energy decline instead of continued exponential growth. This represents a shift in the ontological way in understanding the growth of industrial civilizations and that the future will be different. As such, the purpose of the research produced in this dissertation, was to inform curricular reformists, developers, teachers, researchers and other stake holders to prepare future generations for fossil energy constraint and that past trends were no longer valid predictors of future growth.

Some of prominent observations and pedagogic implications that have emerged from this dissertation are as follows:

Pedagogical Implications that Relate to Fossil Energy

- With fossil fuel, sourced growth period currently peaking and about to head into decline humanity must learn to redesign a civilization different from how it grew (Tainter and Hoekstra, 2003; Wells, 2007; Heinberg & Lerch, 2010; Heinberg, 2012a, 2012b; Kumhof & Muir, 2014; Matsumoto, Voudouris & Andriosopoulos, 2014; McGlade & Ekins, 2014; Turner, 2015).

Implications: Students who are born into one lifestyle will work and raise families in another and retire into a third. These students can likely expect constant declining energy change throughout their lifestyle.

• EROI and net energy research must aggressively investigate economies, transportation, food production, specifically everything that is heavily dependent on cheap, high quality fossil energy.

Implications: Students must become aware of the energy footprint of all parts of their lives and how to create lifestyles minimizing potential disruption from an expected rapid change away from fossil sourced energy.

• Net energy analysis indicates that all activities revolving around usage of cheap fossil fuel will end faster than its decline in production (Hall et al., 2009; Korowicz, 2011; Hall et al., 2014).

Implications: This transition could occur in less than one generation and students must be prepared for the rapidity of this change. Education, infrastructure, lifestyles, food production and shelter need to establish a flexibility enabling adaptation to this rapid change. Programs preparing students for employment in high energy consumptive industries need to be carefully rethought since this looks to end as a tragic waste of human potential and resources expended for on this education.

• Murphy, (2010) and Dale et al., (2011) have pointed out that economic correlation to energy consumption dictates that in a few years, fossil energy decline will impact global economies and that all replacement energetic sources are considerably lower in both EROIE and energy density and is handicapped by its dependency on fossil energy to produce.

Implications: Future student will be impacted by a shrinking economy, a likelihood of increasing student debt and from graduating into poorer paying jobs to repay this debt. Fossil energy will gain in importance as its foundation in creating, maintaining and retiring renewable energy source infrastructure that will allow for energy based civilizations to continue.

Pedagogical Implications that Relate to Climate Science

• The physics and chemistry at the foundation of climate science has been known for nearly two centuries. Foundational works were created by Joseph Fourier, 1824, 1827, John Tyndall, 1861 and Svante Arrhenius, 1896.

Implications: An inordinate amount of time resources and effort is being expended to support an anti-anthropogenic global warming position for which there is no scientific justification. Attacks on climate science teachers and on climate scientists research as is now unfolding in the USA and around the world is not justified and needs to be challenged.

• The Holocene characterized as a Climate Paradise $\Delta T \approx 1°C$, emerged from a period of Global Chaos having a $\Delta T \approx 20°C$ variability. Climate change is non-linear and continued addition of GHG to the atmosphere increases the risk of a globalized climate departure into a hotter planet of chaos and unpredictability.

Implications: Pedagogic approaches to teach non-linear complex systems must be introduced early into the K-12 system to enable students to gain a better understanding of the variability and un-predictability of non-linear systems. This should include an awareness of climatic tipping points that could shift the earth into a hotter climate irrespective of human efforts to mitigate GHG emissions.

Pedagogical Implications that Relate to Economic Issues

• Options to BAU linked GDP must be rethought to address qualities of life over prioritizing an economic health currently measured as an aggregate of market transactions and that has no distinction of what is beneficial or harmful (Kubiszewski et al., 2013; Coyle, 2014; Wiedmann et al., 2015; Alexander, 2016).

Implications: Educators and students need to ontologically reframe away from a GDP focused economy where economic health correlates with (fossil) energy consumption to instead embrace the future of decarbonization. Pedagogical practices must explore and not allow to be diminished programs such as art, music, theatre, gardening and others that work to create community resilience and happiness.

• Unsustainable systems will not disappear to make room for sustainable systems until their ontological framework of beliefs and the norms driving continued support transition from a "neoclassical, capitalist political economy that must grow or die" (Ehrenfeld, 2008b, pp. 3).

Implications: Pedagogy must make clear what represents wasted, useless and uneconomic growth and that the BAU mindset encouraging short term quarterly profits must be refocused into one of long term sustainability goals and objectives.

• Runaway consumerism (a major driver in carbon emissions) requires students to be aware of sufficiency needs to contrast excess consumerism and over-consumption (Crocker, 2013).
Implications: Pedagogy must continue to challenge the BAU need for growing consumption to be replaced by one of meeting needs for human sustenance.

• LTG stabilization of population and industrial production requires an ontological change away from BAU growth.
Implication: Educators need to engage students for a rapid transition through degrowth and behavioral change to reduce energy demands that can be supplied through renewable sources and to reduce humanity's footprint to one that can be sustained by the ecosystem.

There exists significant risk that much of the ontological wisdom that guided humanity as a high energy consuming civilization is obsolete. Ontological and epistemological pedagogic alternatives are needed that move away from the consumptive growth ontologies and towards encouraging sustainability focused living (Sterling, 2001; Hostetler, 2005; Selby, Jones & Kagawa, 2009; Spring, 2009). Pedagogy is needed to nurture a holistically structured pathway that focuses upon understanding systemic connections that complexity has hidden away from sight. This means that fossil energy literacy cover not only quantitate measures such as economics, peak energy, pollution, food and toxicities, but also explore complex ecological questions (Orr, 1992; Funtowicz & Ravetz, 1997; Gadotti, 2000; Stone and Barlow, 2005; Miller, 2007; Sterling, 2008; Evans, 2009; Pelletier, 2010; Nicholson et al., 2012; Pellegrini, 2012).

Some Concluding Thoughts

Writing this dissertation has been a theoretical challenge to navigate through multiple and contested ontological frameworks. Foremost, my introduction to fossil energy descent through the works out of the organization of ASPO-USA and ASPO-International run by industry petroleum and fossil energy specialists, was in error in their projecting the impact of fossil fuel descent due to the rapidity of development in unconventional resources. In hindsight, it can be argued that they overlooked the economic influence of governments in their implementing a zero-interest rate policy (ZIRP) and negative interest rate policy (NIRP) along with other cheap financial resources to boost growth driving the production of uneconomic unconventional liquid fossil fuels. Second, both the conservative nature of IPCC and the corporate/political challenges facing COP from both industry and governmental agencies has worked to derail and hinder transition away from fossil fuel consumption, which some argue that progress in trying to understand and create effective strategies for a post-carbon transition have been delayed tragically. Third is the vested interests in the BAU economy where limitations to understanding the true risks are created due to different analysis from dozens of different competing economic disciplines and due to some working to deliberately create public confusion allowing continued pursuit of what appears to be BAU fossil energy use at any cost.

Perhaps the greatest challenge is in defining the role of education and higher education and asking if it is to serve the public or BAU interests. The emergence of neoliberal education has rapidly grown to one of global dominance and begs a serious question: “are valuable financial and human resources being squandered in support of an ontology destined to fail?” EROIE and net energy both dictate a future of declining resources yet BAU interests are increasingly being directed to sustain the unsustainable. The past generation has witnessed a decline in government support in educational funding, a significant rise in student debt and a rapid emergence of a university business model of consumers and providers. Do educators wish their role to be relegated to one of “let’s make a business deal” in support of an ontology of growing subservience to BAU rather than prepare for real world challenges? I would argue that it is the role of the university to engage and embrace uncertainty which to me means research is going to be messy, crossing boundaries and disciplines even starting out with works as bricolage until greater understanding can be attained to construct better ontological framings. Research must critically focus on the likely future that includes de-globalization, degrowth, energy decline, sustenance not consumption, the building of sustainable and low energy infrastructure and creating a new economics for a degrowth world.

As for “what do I teach?”, when in the classroom, I tell my students the future is not one of hopelessness and despair but rather the industrial civilization appears to be on the threshold of a post carbon renaissance where those who embrace its challenges will be those who create the future. The key implication of this single message is that the future is about change though the mitigation of harmful actions and in adaptation of dictated future changes.

For any challenging the BAU future, they must hold dear to the truth that anything created by humans can be changed. Failing to address these challenges will not change any future reality, rather it means that humanity only has less time and resources to begin to transition, increasing the risk that we will be left with diminished options. Identification of these challenges requites one to critically analyze their sources of information, to search out what ontology guides the work they are reading or watching and to identify the purpose it was originally created for.

Reality as presented to my students becomes one of confronting challenges and during this age of great transition, they are given the opportunity to be positioned in the forefront in this emergence into a new world. Understanding this reality implies that they do so from multiple perspectives. Disciplinary approaches to viewing the world has arisen out of convenience but they must be aware that reality might not be encompassed by isolated disciplines.

Future Research Questions:

Some questions that need further research and investigation are:

- What knowledge becomes valuable in a post-carbon, low energy lifestyle? How do we generate greater focus on researching and uncovering this knowledge?
- How much of our present education has been optimized to serve BAU fossil energy growth interests? Are we teaching stranded knowledge to support BAU interests? This question follows in extension of the concept of strand fossil energy assets in that knowledge that has been invested in might be needed to be abandoned and never used, since it serves a future that must not be pursued.

Sustainability focused research should not be an addition to current curricula, rather it should be a new vision, pathway or gateway to a different way of thinking and as he states, “a different view of curriculum, of pedagogy, of organization change, of policy and particularly of ethos (pp. 50)”. Sterling (2004)

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