

**Synapse**  
Energy Economics, Inc.

## **Benefits of Beyond BAU**

**Human, Social, and Environmental  
Damages Avoided through the Retirement  
of the US Coal Fleet**

January 25, 2011

Prepared for  
**Civil Society Institute**

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<b>1.</b>	<b>EXECUTIVE SUMMARY .....</b>	<b>4</b>
	<i>Premature Death</i>	7
	<i>Water</i>	8
	<i>Social Cost of Carbon</i>	9
	<i>Coal Waste</i>	9
	<i>Nuclear Waste</i>	10
	<i>Conclusions</i>	10
<b>2.</b>	<b>INTRODUCTION.....</b>	<b>11</b>
	2.1. JUSTIFICATION .....	12
	<i>Definitions</i>	14
	<i>Caveats</i>	14
	2.2. SCENARIOS .....	15
	<i>Reference Case</i>	15
	<i>Transition Scenario</i>	15
	2.3. MONETIZING EXTERNALITIES: VALUING LIFE AND THE ENVIRONMENT .....	16
	2.4. MODELING PLANT RETIREMENT IN THE TRANSITION SCENARIO .....	17
<b>3.</b>	<b>HEALTH .....</b>	<b>20</b>
	3.1. BACKGROUND: HEALTH IMPACTS FROM COAL COMBUSTION .....	20
	3.2. METHODOLOGY: HUMAN HEALTH IMPACTS .....	22
	<i>Estimating the Benefit of EPA Clean Air Act Regulations</i>	22
	<i>Modeling Human Health Benefits of the CSI Transition Scenario</i>	23
	3.3. HUMAN HEALTH BENEFITS OF THE TRANSITION SCENARIO.....	24
	3.4. VALUE OF HEALTH BENEFITS RELATIVE TO THE REFERENCE CASE .....	26
	<i>Value of a Statistical Life</i>	26
	<i>Monetary Value of Health Benefits of the Transition Scenario</i>	27
<b>4.</b>	<b>WATER USE AND CONSUMPTION.....</b>	<b>30</b>
	4.1. BACKGROUND: WATER USE FROM THERMAL ELECTRIC GENERATORS .....	30
	<i>Water Scarcity, Water-Use Conflicts, and Climate Change</i>	30
	<i>Power Plant Cooling Systems</i>	32
	<i>EPA Water Use Regulations</i>	34
	4.2. METHODOLOGY: ESTIMATING WATER USE.....	34

4.3. WATER USE AVOIDED THROUGH THE TRANSITION SCENARIO .....	35
4.4. VALUING THE EXTERNALITY COST OF WATER.....	39
<b>5. SOCIAL COST OF CARBON .....</b>	<b>41</b>
5.1. BACKGROUND: CLIMATE CHANGE AS AN EXTERNALITY .....	41
<i>Damages from Climate Change Associated with Greenhouse Gas Emissions</i>	41
<i>Damages from Climate Change</i>	42
5.2. VALUE OF AVOIDED CO <sub>2</sub> EMISSIONS .....	43
<i>Damage Costing</i>	43
<i>Marginal Abatement Cost</i>	43
5.3. AVOIDED CO <sub>2</sub> EMISSIONS IN THE TRANSITION SCENARIO .....	44
<b>6. TOXIC WASTES FROM COAL ASH.....</b>	<b>46</b>
6.1. BACKGROUND: TOXIC COAL ASH AND WASTES .....	46
<i>Catastrophic Failure at the TVA Kingston Plant</i>	46
<i>Coal Ash Toxicity</i>	46
<i>Exposure to Coal Ash and Wastes</i>	47
<i>Managing Coal Wastes</i>	48
6.2. METHODOLOGY: ESTIMATING COAL ASH WASTE PRODUCTION.....	48
<i>Use of Coal Wastes</i>	49
<i>Estimating Coal Waste Generation</i>	50
6.3. COAL ASH AND WASTE AVOIDED THROUGH THE TRANSITION SCENARIO .....	50
6.4. VALUING THE COAL ASH EXTERNALITY .....	52
<b>7. HAZE AND VISIBILITY.....</b>	<b>53</b>
7.1. BACKGROUND: REGIONAL HAZE .....	53
7.2. COMPONENTS OF REGIONAL HAZE .....	54
7.3. THE SOCIAL COST OF REGIONAL HAZE AND REDUCED VISIBILITY .....	56
<b>8. NUCLEAR WASTE AND RISK .....</b>	<b>59</b>
8.1. BACKGROUND: LINGERING DOUBTS ABOUT NUCLEAR RISK AND WASTE.....	59
<i>Externalities of the US Nuclear Fleet</i>	59
<i>Nuclear Waste</i>	61
<i>Nuclear Accidents</i>	64
<i>Upstream Costs: Mining, Milling, and Processing</i>	65

8.2. AVOIDED NUCLEAR WASTE IN TRANSITION SCENARIO..... 66

9. **CONCLUSIONS** ..... 68

# 1. Executive Summary

The existing coal fleet in the United States exacts an expensive toll on the US. The fleet itself is fairly inexpensive to operate, and for years has been a source of cheap electricity for utilities. However, we know now that each year, this coal fleet poisons our lungs with acid gasses and toxic particulates, causing thousands of premature deaths each year. The fleet burdens waterways with millions of tons of leaching coal wastes, heats hundreds of waterways with thermal effluent, consumes millions of acre-feet of water, and releases the largest fraction of emissions which poise us on the brink of catastrophic climate change. These costs, as dramatic as they may be, are almost completely hidden from the public view and are invisible to consumers. As such, the costs are typically “external” to the cost of doing business. Utilities and consumers who do not see these costs fail to account for the full economic impact of their electric choices.

A companion report entitled “Beyond BAU” (2010) found that the full coal fleet could be retired and replaced by 2050 at no net cost to ratepayers (relative to a business-as-usual trajectory), even without accounting for these external costs. This report illustrates just some of the costs from which ratepayers have been insulated and estimates the degree to which these costs could be avoided by 2050 relative to the BAU.

Each year, the existing coal fleet is responsible for:

- Between 8,000 and 34,000 premature deaths from inhaling fine particulate matter from coal combustion
- Over 40 trillion gallons of water withdrawn from surface and groundwater,
- Nearly a trillion gallons of water consumed by coal plant cooling systems, representing well over two thousand gallons for each person in the US;
- About 100 million tons of toxic coal wastes dumped into landfills, sludge ponds, and holding ponds;
- Impaired visibility at the great US national monuments and parks;
- Two billion tons of carbon dioxide, the primary cause of global climate change, drowning coastal regions, reducing water availability in water-short regions, and causing the extinction of an estimated 20-30% of plant and animal species.

The external costs of burning coal are real and substantial. The extraordinary social cost of the annual 8,000 – 34,000 premature deaths, when valued by federal standards, imparts a cost on society of \$64 to \$272 billion; this cost is up to four times as expensive as the cost of electricity from coal.

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***...the social cost of premature deaths...is up to four times as expensive as the cost of electricity from coal.***

Today, the EPA is looking to implement a series of tough environmental reforms in the electricity sector, including regulations governing

emissions, water use, and coal ash. These regulations, implemented individually, would address some of the externalities described here, but would fail to capture all of the external costs.

It is likely that the cost of investments to adequately address all of the damages from coal combustion would greatly exceed the marginal costs of transitioning to a clean energy economy. A comprehensive re-engineering of the way we use and generate electricity may very well be the most economically prudent choice. For every unit of coal which is phased from the US electricity economy, we avoid both extensive social damages as well as the requirement to remediate those damages through high-cost patchwork environmental controls.

***It is likely that the cost of investments to adequately address all of the damages from coal combustion would greatly exceed the marginal costs of transitioning to a clean energy economy.***

This report compares the external costs of generation in the existing coal fleet in two forward-looking scenarios through 2050:

- **Reference Case:** US energy demand continues to grow over the next four decades, and is met with resources which largely echo the composition of today's fleet, with coal, gas, wind and biomass increasing to fill the gap;
- **Transition Scenario:** Rising demand is met through 2030 with modest energy efficiency, and reduced through 2050. Coal is phased out completely by 2050, replaced largely by wind and solar PV.

The Reference Case examines the external costs of the existing coal fleet, including new coal units brought online over the next decades and currently proposed EPA rules (the Transport Rule). These costs are compared against the savings imparted by moving to the Transition Scenario.

**Table 1** shows the external damages imparted by coal generation in 2008.

Table 1. Quantified Physical Externalities of the US Coal Fleet in 2008. <sup>1</sup>

	Capacity (GW)	Generation (TWh)	Premature Mortality (Statistical Lives)	Water Withdrawals (B. Gallons)	Water Consumption (Billion Gallons)	Coal Waste ('000 Tons)	FGD Waste ('000 Tons)	High Level Nuclear Waste (Tons)
NORTHEAST	5	35	134	1,470	2	1,488	701	762
ECAR/MAIN	142	802	4,780	19,311	352	39,194	21,944	750
SERC/FL	88	523	1,833	13,159	201	24,582	9,349	1,159
SPP/ERCOT	37	244	485	4,082	140	12,600	6,459	183
MAPP	14	91	304	2,119	31	4,660	1,555	101
NWPP	13	88	77	308	53	4,235	3,205	40
SW/RM	17	110	115	480	73	8,063	2,544	85
CALIFORNIA <sup>2</sup>	2	14	5	12	7	778	215	162
<b>Total</b>	<b>318</b>	<b>1,910</b>	<b>7,732</b>	<b>40,941</b>	<b>858</b>	<b>95,598</b>	<b>45,972</b>	<b>3,242</b>

Comparing the Reference Case against the Transition Scenario in 2050, the avoided externalities exceed the external damages realized in the system today, except in the area of premature mortality. In this area, the EPA is currently proposing rules which will reduce human health damages. These EPA rules are considered as part of the overall analysis as internalized costs (i.e. the generators must comply and reduce their emissions in accordance with the rule). This rule avoided nearly half of the premature deaths caused by coal plant emissions by 2020. By 2050, the “Reference Case” will have built a significant new fleet of coal generators, which increase the premature deaths again. However, once the EPA rules are implemented and enforced, we do not experience the same level of premature death as today.

Table 2 shows the external damages avoided by the Transition Scenario in 2050.

<sup>1</sup> Regions represent semi-autonomous power regions: Northeast includes NY and NE; ECAR/MAIN includes from the Eastern Seaboard states through the Great Lakes, extending to the Mississippi River and Kentucky. The SERC/FL region includes all Southeast states through the Mississippi River and Florida; SPP / ERCOT includes Kansas, Oklahoma, and Texas; MAPP includes the upper-Midwest and Plains states; NWPP encompasses from Washington through Wyoming and Montana, down to Nevada and Utah. The Southwest includes Arizona, Colorado, and New Mexico; California stands as a separate electric entity.

<sup>2</sup> It should be noted that two power plants (Navajo, AZ and Intermountain Power Plant, UT) are counted towards California in this analysis because they share a direct connection to CA and CA utilities purchase their power directly.

**Table 2. Quantified Physical Externalities Avoided by the Transition Scenario in 2050**

	Capacity (GW)	Generation (TWh)	Premature Mortality (Statistical Lives)	Water Withdrawals (Billion Gallons)	Water Consumption (Billion Gallons)	Coal Waste (Thousand Tons)	FGD Waste (Thousand Tons)	High Level Nuclear Waste (Tons)
NORTHEAST	7	45	77	1,478	10	1,851	1,515	644
ECAR/MAIN	177	1,061	3,550	19,518	559	49,277	47,567	-
SERC/FL	122	754	1,381	13,344	386	33,802	22,883	311
SPP/ERCOT	46	311	461	4,136	194	16,869	8,628	156
MAPP	19	126	261	2,146	58	6,373	3,465	-
NWPP	18	119	99	333	77	5,916	4,204	40
SW/RM	32	214	198	563	156	14,760	4,146	85
CALIFORNIA	2	17	6	14	8	905	251	162
<b>Total</b>	<b>422</b>	<b>2,647</b>	<b>6,033</b>	<b>41,531</b>	<b>1,448</b>	<b>129,753</b>	<b>92,659</b>	<b>1,398</b>

### **Premature Death**

The premature deaths from electrical generating units (EGU) shown here (7,700 in 2008) are derived, in part, from a report issued by the National Research Council (NRC) of the National Academies of Science (NAS), and represent an independent assessment of the health impacts from the existing coal fleet. The mortality estimates are derived by estimating where emissions travel, the population exposed to those emissions, and the health impacts of those emissions. The methodology for accomplishing this task is fairly well established and used by the EPA for the purposes of evaluating policy efficacy. The NAS report, however, falls at the lower end of emissions impacts on mortality. The EPA and the Clean Air Task Force (CATF) have both issued independent reports which find mortality estimates around 34,000. Therefore, the estimate used here is definitively at the conservative lower end. Nonetheless, the fact that statistically, nearly 8,000 lives are lost to emissions from coal plants each year represents a massive cost to society on an annual basis.

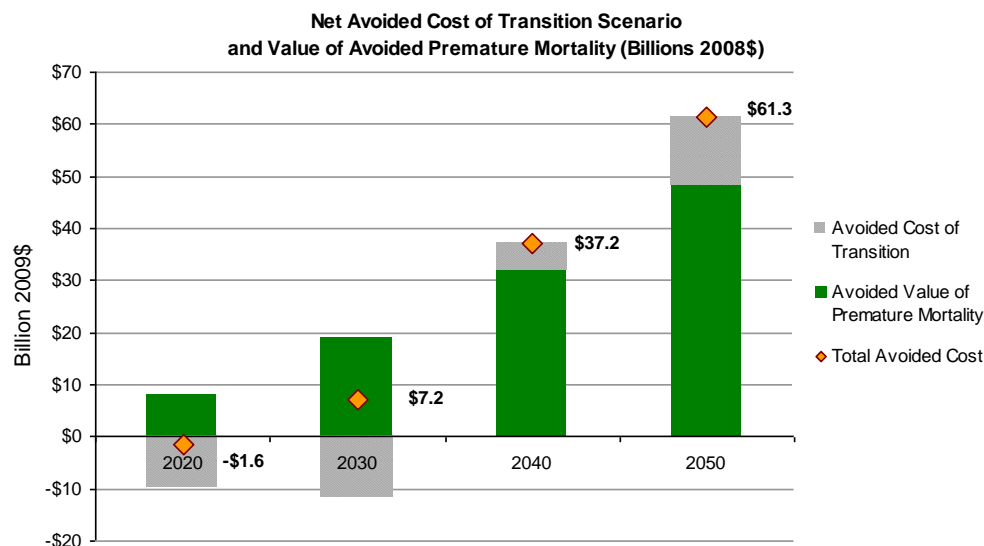
The EPA and others have estimated a cost associated with poor air quality leading to premature death. The “value of a statistical life” (VSL) is a rough estimate of how much individuals value the reduction of risk in their own lives. The EPA has estimated a VSL of approximately \$4.8 million in 1990\$ at 1990 income levels; translated into 2008\$ and current income, we estimate an approximate VSL of \$8 million. Therefore, the nearly 8,000 premature deaths caused annually by coal today cost society on the order of \$62 billion dollars per year.

If we use the higher mortality estimate from the EPA and CATF, premature deaths from coal combustion emissions costs society about \$270 billion on an annual basis in 2008.

Our analysis estimates that by retiring the entire coal fleet, we avoid 6,000 premature deaths per year, with an *annual* benefit of approximately \$48 billion by 2050. These benefits are incremental to the net tangible costs and benefits of the Transition Scenario itself. The net costs of the Transition Scenario are nearly outweighed by the human



health benefits of retiring the least efficient generators in 2020, and far outweighed by retiring the next set of least efficient generators by 2030 (see **Figure 1**).



**Figure 1. Net avoided cost of transition scenario with value of avoided premature mortality relative to the reference case.**

The net incremental cost of retiring the first set of coal generators, under \$2 billion, is a *de minimis* cost relative to an electric industry which saw retail sales of nearly \$346 billion in 2009.

### **Water**

The coal fleet uses significant amounts of water. Once-through cooling systems on coal plants along coastlines, along major waterways, and on lakes and reservoirs draw massive quantities of water to cool boiler steam, and then discharge this water back into estuaries and rivers at higher temperatures.

***... in 2008, the coal fleet withdrew nearly 41,000 billion gallons, more than half of the volume of the Ohio River...***

This pattern of water use impinges fish and shellfish on filter

screens, cooks their eggs and larvae in heat exchangers, and raises the temperature of their ecosystems. Whether we value these waterways for commercial or sport fishing, or rely on the ecosystem services which they provide (such as clean water), water withdrawals from the coal fleet have significant, as of yet unquantified, cost.

We estimate that in 2008, the coal fleet withdrew nearly 41,000 billion gallons, more than half of the volume of the Ohio River in 2008. Each gallon which passes through a power plant quickly turns from a habitat to a steamer in the flash of a heat exchanger.

A fairly small fraction of these withdrawals (2%) is consumed by the electric sector. While it appears as a small value, the 860 billion annual gallons in 2008 and 1,450 billion

gallons in 2050 represent important waters which are otherwise not available for consumption, agriculture, and ecosystems.

The large withdrawals of fresh and coastal waters could be avoided through either costly environmental retrofits, or by retiring the coal fleet. We estimate that by 2030, the Transition Scenario would avoid 42 trillion gallons of water withdrawals each year, and 1.5 trillion gallons of water consumption each year from the coal fleet.

### ***Social Cost of Carbon***

Emissions of carbon dioxide from the combustion of coal and other fossil fuels contribute to irreversible climate change. Scientists and economists predict that the effects of climate change will be widespread and economically damaging, and further, that the extent of the predicted damages is highly dependent on emissions from combustion today and in the near future. The total accumulated cost to society from the effects of climate change include damages to cities and infrastructure from rising sea level, droughts, heat waves, and severe weather is considered the “Social Cost of Carbon”. Monetizing the broad damages to ecosystems, the large number of directly or indirectly lost and displaced lives, and extinct species is a fraught task.

Damages from climate change cannot be avoided without significant changes to the coal fleet: either we curtail coal generation completely, or capture all of the carbon dioxide emitted (and more) by the existing and future coal fleet. The prospects for carbon capture and sequestration (CCS) are distant and expensive; retiring the existing fleet takes a significant step towards reducing the social cost of climate change.

### ***Coal Waste***

The US generates about 250 million tons of municipal solid waste (garbage) each year, about 135 million tons of which is disposed of in landfills.<sup>3</sup> By way of contrast, we estimate that coal utilities generate 140 million tons of coal combustion and flue gas desulfurization (FGD)<sup>4</sup> waste. About 35% of that coal waste was re-used or sold for other purposes, the remainder ends up in sludge ponds and landfills. Today, the US coal fleet dumps the equivalent of two-thirds of all the landfilled municipal solid waste generated in the US.

However, there is a critical difference between municipal and coal wastes. Coal wastes are toxic. Reports have found leaching and leaking into local groundwater, and in 2008 a TVA coal ash pond in Tennessee burst, spilling over a billion gallons of sludge into the Emory River, five miles upstream of the Tennessee River. It is highly uncertain what environmental consequences may stem from either the major spill or slow leakage out of numerous coal waste ponds throughout the US, but universal concern at the TVA spill suggests a high value on remediating coal waste.

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<sup>3</sup> US EPA. 2009. Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Table 1 and 29. <http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2008data.pdf>

<sup>4</sup> FGD units are “scrubbers” attached to some coal plants to remove toxic sulfur dioxide from flue gasses. The FGD units create large volumes of waste in the process.

While the existing stockpiles of coal waste will have to be remediated, the Transition Scenario avoids 220 million tons of waste annually by 2050.

### ***Nuclear Waste***

It is estimated that the US nuclear fleet produces over three thousand tons of high level radioactive waste each year: wastes which currently have no permanent repository and continue to be stored in essentially temporary storage vessels. The social concern of maintaining these vessels and the danger posed to both populations today and in future generations exacts a high cost on society.

The Transition Scenario is oriented towards reducing nuclear generation where renewable energy resources can otherwise be mobilized. In the Reference Case, nuclear generation, and hence waste, grows moderately. Therefore, the Transition Scenario is able to save approximately 1,400 tons of high level nuclear waste generation each year.

### ***Conclusions***

The companion paper to this report, “Beyond BAU” put forward a feasible pathway to retire the entire coal fleet by 2050. The

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***Today, the public bears a heavy social tax on behalf of coal consumers. The Transition Scenario begins to correct a pronounced market failure, and balances resource needs with costs.***

report found that the cost of transitioning to a clean energy economy had a low absolute marginal cost above a business-as-usual trajectory, but provided a significant benefit of reducing the US carbon footprint 80% relative to 2010 by 2050. This report shows that the co-benefits of retiring the coal fleet are very large, including not only carbon benefits, but benefits to human health by cutting toxic emissions from coal generators, benefits to fisheries and aquatic ecosystems through reduced water consumption, and a far lower burden of toxic coal-ash waste.

This report begins to quantify some of the externalities of the current coal fleet and the benefits of retiring the fleet over the next decades. The externalities identified here are real, significant, and large. When utilities ignore carbon and toxic emissions, continue to withdraw and consume enormous volumes of water, and dispose of toxic waste in unsafe reservoirs, the cost of social burdens is shifted to society. Today, the public bears a heavy social tax on behalf of coal consumers. The Transition Scenario begins to correct a pronounced market failure, and balances resource needs with costs.

## 2. Introduction

The US electric power sector faces a series of new challenges in 2010. About half of the US generating fleet is comprised of coal-burning power plants, which are together the largest single contributor to greenhouse gas emissions, emit toxic and environmentally damaging gases and metals, consume massive quantities of water, and leave behind flattened mountaintops and lakes of sludge and waste. First given notable voice in the 1970s, some of these concerns helped implement the Clean Air Act (CAA) and the Clean Water Act (CWA). Today, these concerns are at the heart of the debate on how to effectively combat climate change, as well as a series of newly proposed or emerging rules on toxic emissions and water consumption. Whether explicitly stated or simply implied, much of the harm imposed on the environment and society by the US electric generating fleet can be traced directly to coal-burning power plants.

Environmental regulations in the electric sector and proposed legislative efforts to reduce greenhouse gasses are not politically neutral topics. A significant degree of contention is rooted in a disagreement about the relative merits and harm of continuing along a business-as-usual (BAU) trajectory versus the costs and benefits of changing the face of the US electric sector. The question is not clear-cut: coupled with the litany of often invisible environmental harms imposed by today's power fleet are the tangible benefits of a known, tested, and reliable electricity system and the economy which it supports. Conversely, the marked benefits of moving towards efficiency and renewable energy are surrounded by a degree of uncertainty as to how this new system might operate, how much it would cost, and who would bear the brunt of these costs and new infrastructure.

A 2010 report entitled *Beyond BAU: Investigating a Future without Coal and Nuclear Power in the U.S.*<sup>5</sup> ("Beyond BAU") worked to shed light on the tangible costs corner of this political debate. The report outlined a potential pathway towards replacing a portion of US nuclear generators and all coal generators with a diverse portfolio of renewable energy, efficiency, and natural gas by 2050. *Beyond BAU* estimated the total bulk power costs of a following a BAU trajectory (called the "Reference Case")<sup>6</sup>, as well as the costs of a full electric system overhaul (called the "Transition Scenario"). The analysis in *Beyond BAU* worked to create a Transition Scenario which would maintain electric reliability and allow for economic growth, but reduce electric demand through dramatically improved efficiency.

The more subtle and far less tangible questions associated with retiring the coal fleet revolve around non-market costs and benefits of health impacts, water consumption, waste, greenhouse gasses, haze and visibility, and coping with nuclear waste. Each of these categories has a value: as individuals and as a society, we are willing to pay to

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<sup>5</sup> Synapse Energy Economics, 2010. *Beyond Business as Usual: Investigating a Future without Coal and Nuclear Power in the U.S.* Prepared for the Civil Society Institute.

<sup>6</sup> The Reference Case follows a BAU pathway prepared by the US Department of Energy (US DOE), used as a baseline for estimating the impacts of national energy policies.

avoid asthma, prevent chronic lung disease and premature death due to pollution, avoid the incremental and potentially catastrophic impacts of global climate change, see across the Grand Canyon or even a few city blocks, and maintain water supplies for consumption, aquatic ecosystems, and agriculture. However, none of these categories of costs are captured directly in the way we purchase electricity. Our inability to pay for these services (or to prevent harm) represents a serious market failure, and overlooking these costs when evaluating the future of the electric system can be perceived as negligent.

This report explores the physical damages which are currently imposed by the US coal fleet, and waste generated by the nuclear fleet, and traces these damages through the next four decades following the trajectories of the Reference Case and Transition Scenario. We quantify the damages where feasible, and monetize (i.e. assign a dollar value to) damages where there is an agreed-upon methodology and metric; in other categories of damages, we explore the boundaries of the question and propose methods in which the damages could be quantified or monetized.

## 2.1. Justification

The costs and benefits quantified and explored in this paper all fall outside of current market mechanisms: the cost of electricity does not directly take into account the human lives lost due to high emissions and poor air quality, the value of removing water from water-limited areas, killing fish or larvae in cooling intake structures, poisoning groundwater near unlined coal-ash ponds, or the risk of radioactive contamination generations from now from high-level radioactive waste.

Costs which are not realized by the owners, operators, or shareholders of a company are externalities – literally, external to the market. The National Research Council defines externalities as “activit[ies] of one agent (i.e., an individual or an organization like a company) that affect the wellbeing of another agent and occur outside the market mechanism”.<sup>7</sup> The market and economic rationale are powerful agents of change, but externalities are known market failures: the purchasers of a commodity (in this case, electricity) are not exposed to the true cost of business. Externalities can have both positive and negative impacts: environmental and health degradation is clearly a negative impact, but features such as job growth are potentially a positive externality. In this research, we explore a class of negative externalities which are typically not considered in electric planning. These include:

- Health impacts and premature mortality from the US coal fleet
- Water withdrawals and consumption from the US coal fleet
- The social cost of global climate change

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<sup>7</sup> National Academy of Sciences. Hidden Costs of Energy: *Unpriced Consequences of Energy Production and Use*. Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption; National Research Council. National Academies Press, 2009.

- Toxic waste from coal ash
- Haze and visibility impacts from electric sector emissions
- Long-term risks of accumulating radioactive waste and risks of catastrophic nuclear failure

The US National Environmental Policy Act (NEPA) of 1970 first established a national interest in protecting human health and welfare from environmental dangers. It was recognized that a widespread institutional failure to recognize environmental hazards from industry was in all likelihood causing harm to humans, and had caused irrevocable harm to ecosystems which were held to be valuable. The US Environmental Protection Agency was established as the office which would “establish and enforce environmental protection standards” for the purposes of “prevent[ing...] damage to the environment and biosphere, and stimulat[ing] the health and welfare of man”.

With a charge of reducing impacts and damages to health and the environment, the EPA serves a valuable economic role: EPA regulations which are designed to protect humans and the biosphere effectively internalize the external costs, thus correcting a dramatic market failure. The Clean Air and Clean Water Acts exemplify an effort by the Federal Government to intervene in business on behalf of the public good. More specifically, these two acts represent an action to compel businesses, including the electric sector to remediate, and hence “internalize” some of the damages which they impose on the environment or society. For example, requiring states to meet air quality standards, thus imposing emissions limits on fossil power plants, has substantially reduced the social harm caused by these plants – the cost of remediation is paid by electric consumers. Current rules under consideration by the US EPA could limit harmful emissions even further, reduce water withdrawals and consumption, require the remediation of unprotected or leaching coal ash ponds, and even potentially curtail emissions of carbon dioxide (CO<sub>2</sub>); all efforts to internalize the cost of producing power from fossil fuels. The long-running efforts to build a sound nuclear waste repository are evidence of a national desire to internalize the cost of radioactive waste exposure.

However, in the power sector, the EPA has not always acted quickly or decisively. The EPA’s decision-making structure has historically only allowed for incremental improvements in reducing environmental impacts, steps which on an individual basis do not change the fundamental structure of business and thus only accomplish incremental changes. Today, the EPA is looking to implement a series of tough environmental reforms in the electricity sector, including regulations governing emissions, water use, and coal ash. These regulations, implemented individually, would address some of the externalities described here, but would fail to capture all of the external costs. It is likely that the cost to consumers to adequately address all of the social costs of generating electricity from the existing coal fleet would be significantly higher than the marginal cost of simply replacing the existing fleet with clean resources, such as renewable energy and efficient energy use.

The large-scale US EPA rules which may control emissions, water, and waste have not yet been fully promulgated and are years away from implementation (assuming they

survive legal challenges). It is abundantly unclear how rigorously these rules will apply to all actors and how much damage will be remediated or internalized if the rules are enacted. Therefore, we assume that only the most likely emissions reductions rules (the Clean Air Transport Rule, 2010) will be enacted and all other damages remain “external” to the market mechanism.

### **Definitions**

For the purposes of this research, we define “damages” as the physical harm to the environment or society which are outside the market mechanism. Damages include the physical quantity of common resources which are freely allocated to the electric sector (such as water or carbon dioxide levels in the atmosphere). We define “externalities” as the *monetary value* of these damages, when available.

“Avoided damages” refers to the physical harm which is avoided by implementing an alternate to harm-causing agent (i.e. transforming the electric sector); “Co-benefits” are the monetized version of avoided damages.

In context: The electric sector today imposes damages on the environment and society. These damages have an externality cost. Replacing the existing coal fleet with a portfolio of renewable energy, energy efficiency, and gas avoids physical damages and yields significant monetary co-benefits. The purpose of this paper is to quantify these costs and benefits, where feasible.

### **Caveats**

This white paper does not explore upstream costs, including (but not limited to) wastes and environmental harm from coal/uranium mining or gas/oil drilling, manufacturing and consumer waste from replacing old technologies with efficient products, or concerns in production waste from solar PV technologies. In addition, we do not examine potential environmental damages from renewable energy projects, such as landscape of wildlife impacts from wind farms or large solar arrays, or concerns about the landscape visibility of large-scale wind projects.

There are a variety of federal, state, and local rules which are designed to mitigate risk and harm from the electric power sector; all of these impose complicated internalized costs, which we do not seek to differentiate. For example, CO<sub>2</sub> emissions performance standards in California effectively bar the generation of coal-fired power (or its direct purchase from neighboring states). This ruling internalizes a value to the cost of global warming on electric consumers in the state. The costs of these rules are partially reflected in the costs of the electric sector today, as well as the shape of the electric sector in the BAU case.

The purpose of this report is to begin to elucidate the scale of problems which could be avoided through the retirement of the existing coal fleet along the Transition Scenario pathway, and conversely, the new problems which will be incurred if we choose to follow the Reference Case. The research underlying this report is as explicit as possible: we exclusively use widely-available public sources of data and federally accepted metrics for valuing harm, and trace these damages to individual power plants. In the coal

chapters, damages incurred or avoided are linked to 1,016 coal-fired electric generating units (EGU): emissions, health impacts, water consumption, and coal ash and waste production are all linked to individual actors; individual EGU are retired along an economically likely pathway. In the nuclear waste chapter, we connect estimates of nuclear waste generation to current and potential future technologies.

## 2.2. Scenarios

### *Reference Case*

The Reference Case represents a BAU scenario put forth by the US DOE Energy Information Administration (EIA). The scenario represents the DOE's best estimate for what the energy sector could look like through the next two and a half decades, given a series of assumptions about resource availability, the cost of fuel and technology, US policies, and demand. This forecast, known as the Annual Energy Outlook (AEO) maintain a steady assumption about behavior, use, and the economy, and does not represent policies which are not already implemented. The Reference Case used here extrapolates trends from the AEO 2010 from 2035 through 2050.

### *Transition Scenario*

The Transition Scenario represents a gradual but comprehensive re-build of the US electric sector. In this scenario, the country transitions away from coal and nuclear power and toward more efficient electricity use and renewable energy sources. Specifically, coal-fired generation is eliminated by 2050 and nuclear generation is reduced by over one quarter. One important aspect of this scenario is that energy efficiency reduces demand an average of 1.3% per year over the study period, allowing overall generation to fall 10% relative to today and 40% relative to 2050. **Figure 2** shows the expected fuel mix in the Reference Case and Transition Scenarios in 2030 and 2050.



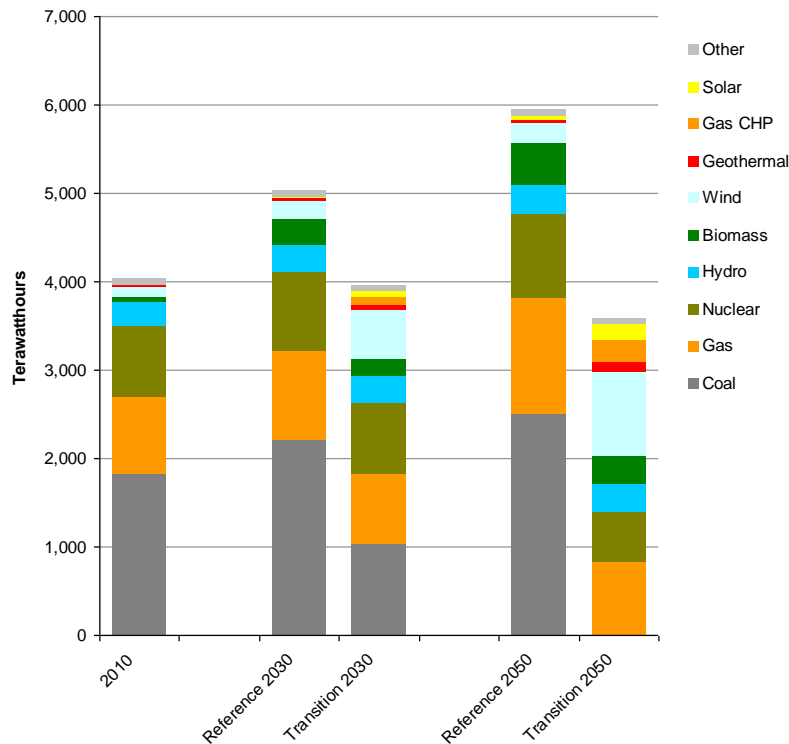


Figure 2. Resource mix in the Reference Case and Transition Scenario

### 2.3. Monetizing Externalities: Valuing Life and the Environment

The purpose of this research is to elucidate the external costs of a BAU and transformative electric sector scenario. External costs are real: tangible damages occur to the environment and society. However, quantifying the damage, much less attaching a monetary (dollar) value to the damage, is a fraught task.

To the extent feasible, in this research we:

- describe the type of human, social, and environmental damage caused by coal and nuclear plants in several categories;
- quantify the amount of damage which occurs under the current system and in the future scenarios, if possible;
- either monetize damages in each scenario, or suggest a method or metric which could be used to attempt to value the damages accrued;
- describe and quantify the avoided damages and co-benefits accrued through the Transition Scenario

Monetizing damages assumes that we have a decent understanding of how to value environmental harm, human health, and life. In many of the chapters which follow, there are no clear guidelines for evaluating externalities: determining the environmental risks of increasingly massive coal-ash piles, the potential harm from rare but potentially

catastrophic nuclear accidents, and estimating reasonable externality costs for water or the wildlife which uses that water are all difficult tasks. Accordingly, we do not attempt to monetize all of these areas.

## 2.4. Modeling Plant Retirement in the Transition Scenario

Not all coal plants are created equal. Plants vary in vintage, from units which are still operating from 1920 to units built as recently as 2008. Plants utilize different coal types, from fairly efficient anthracite to essentially hardened peat, lignite. Newer plants tend to have more efficient boilers, generators, and emissions controls, while older plants may have antique components and are uncontrolled. The efficiency, running cost, emissions rate, water consumption, waste generation rate, and use of waste vary on a unit by unit level. In evaluating the benefits of retiring the existing fleet, the order in which coal plants are expected to be taken offline is potentially quite important: if the dirtiest plants are retired first, then there will be a disproportionately high near-term benefit for each MWh of coal retired. Synapse employed ongoing research into the economics of coal plants to determine which units would be most likely to retire first in each region of the US, assuming that choices are made on the basis of forward-looking economic performance. Plants with the most expensive running cost were preferentially retired, followed by more economic units.

One thousand sixteen (1016) coal units<sup>8</sup> were ranked within regions according to their running cost in dollars per MWh (determined by fuel cost, operations and maintenance, and the capital and O&M costs for new emissions controls required under the Clean Air Transport Rule<sup>9</sup>).

In the Transition Scenario analysis, blocks of generation were retired by cost, meeting the trajectory stipulated in the Transition Scenario; each region follows a roughly economic retirement schedule independently of all other regions. Generally speaking, the retirement schedule targets the smallest and oldest plants first (see

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<sup>8</sup> A “unit” is defined as here as the generator. At any given plant, there may be multiple generators, some of which use different fuels. There were 1,416 primarily coal-burning units which were operational and reporting to the Energy Information Administration (EIA). Four hundred of these units are process boilers, used at industrial sites, and are therefore classified by the EIA (and in the Transition Scenario) as co-generators. These 400, which in 2008 generated less than 5% of coal fleet electricity, are excluded from this analysis.

<sup>9</sup> Operations and maintenance (O&M) costs are divided into variable and fixed costs: the former are costs which scale with the output of the plant, and the latter are costs which the plant incurs, regardless of the level of operation. Fixed costs, such as employee salaries and property taxes, are important on a per MWh basis for plants which operate at very low capacity factors: there are fewer MWh over which to spread fixed costs.

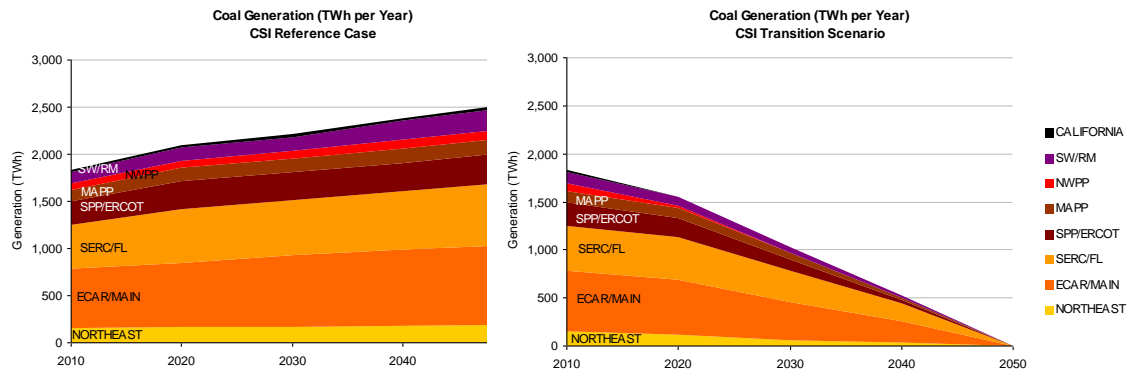
**Table 3)**, meaning that larger number of small plants are retired in early years.

**Table 3. Characteristics of Retiring Units in Transition Scenario**

Time Period of Retirement	2010-2020	2020-2030	2030-2040	2040-2050
Vintage	1959	1962	1973	1974
Capacity (MWe)	106	198	465	571
Capacity Factor (%)	55%	65%	71%	73%
Number of Units	325	354	175	162

In the Reference Case, new coal generators were added to the fleet with similar operating characteristics to the ten largest generators in each region. It was not feasible to determine where new generation will be developed over the next four decades to meet the Reference Case expectations, and therefore the current locations of the ten largest generators were considered to be a reasonable expectation for citing new plants.

**Figure 3**, below, shows the trajectory of coal generation in each region according to the CSI Reference Case (left) and Transition Scenario (right), as implemented in this Benefits analysis.



**Figure 3. Coal generation in TWh for the Reference Case and the Transition Scenario.**

The presence or absence of individual generators is used to determine the annual health impacts, water withdrawals and consumption, and coal ash generation.

## 3. Health

### 3.1. Background: Health Impacts from Coal Combustion

Poor air quality has human health impacts, causes environmental damage, and reduces visibility. The most notable, and expensive, impact from poor air quality is premature mortality, caused by respiratory and cardiovascular damage, both acute and chronic. This damage is linked to fine particulate matter (PM), classified in a size range of less than 2.5 micrometers<sup>10</sup> (PM<sub>2.5</sub>) and less than 10 micrometers (PM<sub>10</sub>), with much of the damage linked to PM<sub>2.5</sub>. A large portion of human-caused particulate matter is derived from the combustion of fossil fuels in power plants (stationary sources) or vehicles. Some of this pollution is primary, meaning it is formed at the stack or tailpipe, and a large fraction is secondary, meaning that the pollution is formed in the atmosphere from products released from the stack, particularly oxides of nitrogen (NO<sub>x</sub>) and sulfur dioxide (SO<sub>2</sub>).

The EPA regulates emissions of PM, NO<sub>x</sub>, and SO<sub>2</sub> as criteria pollutants, or air pollutants known to cause harm. The US power sector produces a significant fraction of criteria pollutants in the US (18% of NO<sub>x</sub> and 66% of SO<sub>2</sub> in 2008).<sup>11</sup> Nearly all of the SO<sub>2</sub> emissions (99%) and more than 93% of NO<sub>x</sub> emissions from the power sector are from coal combusting generators.<sup>12</sup>

The EPA assesses the efficacy of regulations by estimating the costs of compliance against the benefits of the regulations. When assessing the benefits, the EPA takes into account a limited set of externalities<sup>13</sup> which are avoided by the regulation, including premature mortality. By valuing the avoided cost of lives lost against the cost of implementing the regulation, the EPA can demonstrate the cost effectiveness of regulations which save lives. This valuation of life is a critical component of current policy-making structure, and provides a useful avenue to discuss the benefits of the Transition Scenario.

In 2009, the National Research Council (NRC) produced a report entitled “Hidden Costs of Energy”, which estimated monetary damages from the coal and gas fleets in 2005.<sup>14</sup> The NRC estimated a social cost of approximately \$62 billion for the coal fleet in 2005. These damages are based almost exclusively on premature mortality, priced at \$6 million per statistical life (2000\$). While it is not stated explicitly in the report, we can

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<sup>10</sup> About 1/30<sup>th</sup> the diameter of a human hair

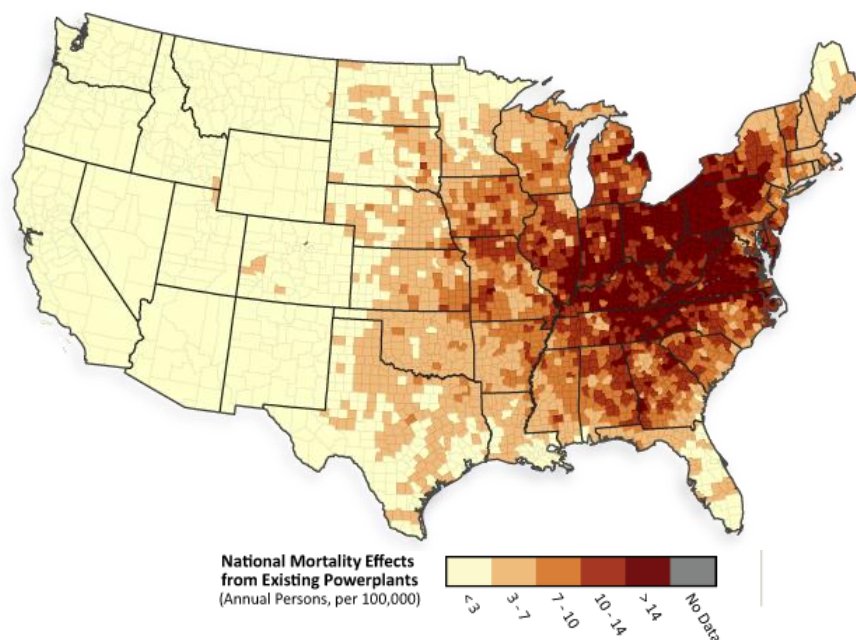
<sup>11</sup> US. EPA. 2008 data. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data: <http://www.epa.gov/ttn/chieftrends/trends06/nationaltier1upto2008basedon2005v2.xls>

<sup>12</sup> US EPA. 2008 data. Clean Air Markets Division (CAMD). Unit Emissions Report, 2008.

<sup>13</sup> Externalities defined here as costs (or benefits) of a commodity to society which are external to the market. In the power sector, external costs are those which are imposed upon the population but are not realized by the owners, operators, or purchasers of power. Therefore, unpriced (or underpriced) air emissions which cause harm are considered externalities. In this paper, we will define externalities as only the costs to society, rather than the net of the costs and the market price of pollution. National Academies Press.

<sup>14</sup> NRC. 2009. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use.

calculate that the NRC has estimated over 10,000 statistical lives<sup>15</sup> lost each year (as of 2005) due to emissions of NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> at US coal power plants.<sup>16</sup> Using a similar methodology, but a different set of assumptions about how health is impacted from emissions, the EPA estimates over 20,000 premature mortalities from coal-fired emissions today.<sup>17</sup> In 2010, the Clean Air Task Force (CATF) and Abt Associates published findings using the same methods as the EPA and NRC, and estimated a current externality of 34,000 premature mortalities due to power plant emissions.<sup>18</sup> The NRC estimates, which are used in this study for convenience, are clearly at the lower bound and a fairly conservative estimate of the premature deaths which could be avoided by retiring the coal fleet.



**Figure 4. National mortality effects from existing power plants, Clean Air Task Force (2010)<sup>19</sup>** Colors represent mortality per 100,000 individuals. Dark colors represent a higher exposure risk.

The CATF analysis of the distribution of premature mortality impacts of existing power generators is shown in **Figure 4**. This figure shows the impact of fine particulate

<sup>15</sup> The epidemiological framework for this research does not explore specific mortality due to air emissions, but instead looks at risks, expressed as a chance of mortality based on a certain level of emissions exposure. Therefore, “statistical lives” is the fractional risk, aggregated over a large population.

<sup>16</sup> The NRC analysis included emissions from primarily co-generating coal-fired units. These co-generators are not included in this analysis, which examines electric generating units only.

<sup>17</sup> Author calculation from Regulatory Impact Analysis of Transport Rule. Pope et al (2002) study estimates a benefit of 5,100 premature mortalities avoided in implementing the Transport Rule (relative to approximately 10,000 premature mortalities in the baseline), while the Laden et al. (2006) study estimates 13,000 avoided premature mortalities. We estimate a total of at least 20,000 annual premature mortalities in the Laden study.

<sup>18</sup> Abt Associates. 2010. Technical Support Document for the Powerplant Impact Estimator Software Tool. Prepared for the Clean Air Task Force.

<sup>19</sup> Clean Air Task Force. 2010. Death and Disease from Power Plants.

[http://www.catf.us/coal/problems/power\\_plants/existing/](http://www.catf.us/coal/problems/power_plants/existing/)

pollution on premature death by county as a fraction of the population. Darker red colors indicate that a higher fraction of the population in the county is at risk. Areas with large population centers in deep red areas will have a larger number of premature mortalities from coal-fired pollution than small populations or areas with less exposure. A vast majority of the harm imposed occurs in the Great Lakes and Appalachian regions through the Southeast, representing the regions exposed to uncontrolled power plant emissions.

### **3.2. Methodology: Human Health Impacts**

To estimate the human health benefits of retiring the existing coal fleet, we estimate the health impacts from the fleet in the Reference Case, including a growing fleet and compliance with proposed 2010 EPA regulations, and impacts in the Transition Scenario, which also requires regulatory compliance as well as coal fleet retirements.

We estimate damages from the existing coal fleet based on data from the above-referenced NRC report. In the report, damages to human health are based on the locations of each coal plant, the emissions from those plants, and the populations which are impacted by those emissions. The federally-sponsored NRC report provides a convenient structure to estimate externalities from each coal generator in the nation, and therefore calculate the benefit of reducing emissions according to a regulatory schedule in the Reference Case, and retiring the fleet according to the CSI Transition Scenario schedule.

#### ***Estimating the Benefit of EPA Clean Air Act Regulations***

The Synapse analysis takes into account regulatory requirements imposed since 2005, and expected changes under future regulations. Regulations promulgated by the EPA since the passage of the Clean Air Act in 1970 have significantly reduced emissions from the US power sector: Both NO<sub>x</sub> and SO<sub>2</sub> emissions have fallen by half since the mid 1990s and 1970s, respectively. In the first years of the Clean Air Act, emissions of primary PM<sub>10</sub> dropped by nearly 90%.<sup>20</sup> The new Clean Air Transport Rule (CATR), proposed by the EPA in 2010, is designed to reduce harm from PM<sub>2.5</sub> and ozone formed in the atmosphere from NO<sub>x</sub> and SO<sub>2</sub> by requiring more stringent controls on the power sector.

Since 2005 alone, national energy-sector emissions of NO<sub>x</sub> and SO<sub>2</sub> have fallen by 21% and 27%, respectively. While we cannot definitively state that this reduction anticipated the now vacated CAIR ruling, it would appear that EPA rules have made significant inroads towards reducing the pollution which causes premature mortality. The Synapse analysis takes into account benefits accrued due to EPA rules requiring more stringent emissions controls.

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<sup>20</sup> US. EPA. 2008 data. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data: <http://www.epa.gov/ttn/chieftrends/trends06/nationaltier1upto2008basedon2005v2.xls>

### ***Modeling Human Health Benefits of the CSI Transition Scenario***

The health damages incurred by the coal fleet are a function of coal generation, plant locations, and emissions. For example, many coal generators in the northeast are controlled for emissions, but these generators are near dense population centers and cause significant harm for each unit of energy produced (on average, nine premature mortalities for each TWh of generation). Coal generators in the West are upwind from large population centers by hundreds of miles, and therefore cause less direct harm for each unit of energy produced (about one mortality per TWh). Finally, there are a large number of uncontrolled generators in the Midwest, and many of these lie upwind from major east coast populations; therefore these generators are responsible for significant damages (see **Figure 4**).

It is important to note that this analysis tracks damages which are incurred *from* each plant, rather than where those damages occur. Because the particulate matter derived from NO<sub>x</sub> and SO<sub>2</sub> are formed in the atmosphere over long distances, damages often occur outside of a region of generation. For example, populations along the mid-Atlantic receive pollution from both proximate generators, as well as generators in the Midwest. For the purposes of this analysis, we associate damages with the generating unit, rather than the place in which those damages occur.

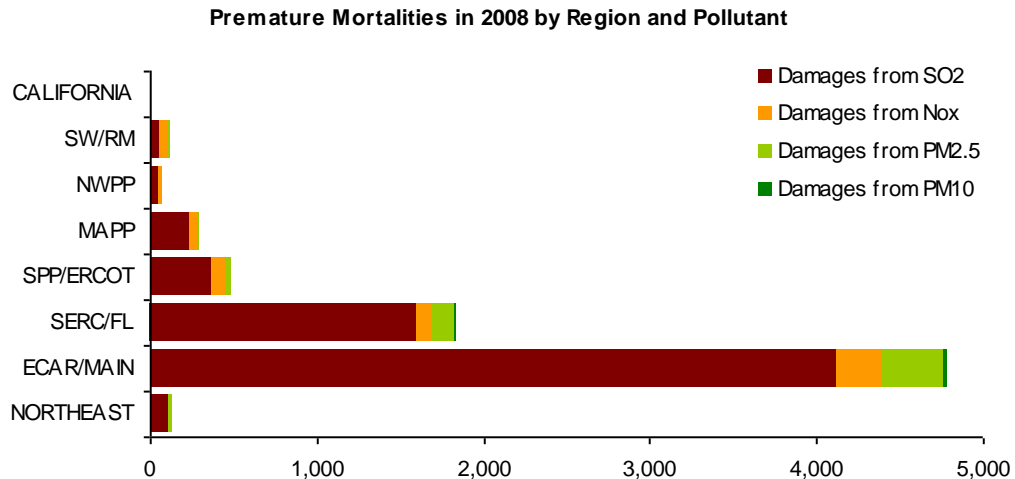
Damages for each coal plant in 2005 were assessed by the National Research Council (NRC) in the publication “Hidden Costs of Energy”. Synapse obtained NRCs estimates of both damages per plant, as well as damages at each plant per ton of NO<sub>x</sub>, SO<sub>2</sub>, [primary] PM<sub>10</sub>, and [primary] PM<sub>2.5</sub>. Each generator was matched to an NRC-assessed plant; generators which had not been assessed by the NRC were assigned per ton damages equivalent to the average in the state. In addition, 2008 emissions of NO<sub>x</sub> and SO<sub>2</sub> were found for each coal unit, as reported to the EPA’s pollutant trading program (CAMD). For lack of information on current primary PM emissions, these emissions were assumed to remain unchanged since the 2005 NRC analysis. Using reported 2008 emissions and the NRC estimates of damages per ton of pollutant at each plant, we estimated the total premature mortalities for each region in 2008 (see **Figure 5**, below)

In total, we estimate 7,700 premature deaths from coal-fired emissions in 2008; a *highly* conservative value relative to estimates from the EPA in evaluating the benefits of the Clean Air Transport Rule.<sup>21</sup>

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<sup>21</sup> The EPA estimates that by cutting SO<sub>2</sub> emissions 71% and NO<sub>x</sub> emissions 51%, the Clean Air Transport Rule would reduce premature deaths by 14,000 to 36,000 in 2014 at a value of \$120-\$190 billion on an annual basis.





**Figure 5. Premature mortality in 2008 by region and primary pollutant.**

For both the CSI Reference Case and the Transition Scenario, we assumed that the currently proposed Transport Rule would be fully implemented by 2020; therefore any plants which had not retired by 2020 would be subject to the rule. The Transport Rule stipulates that most large generators east of the Mississippi River (31 states and DC) will require scrubbers for SO<sub>2</sub> and NO<sub>x</sub> in the next seven years. While there are some exclusion for small generators and process boilers, this ruling reduces emissions markedly. Using EIA-based information, we obtained information on which generators were linked to substantive existing emissions controls and which would require new or additional emissions controls under the transport rule. For those generators which obtain new SO<sub>2</sub> or NO<sub>x</sub> controls, we assume that emissions fall by 90%, respectively.

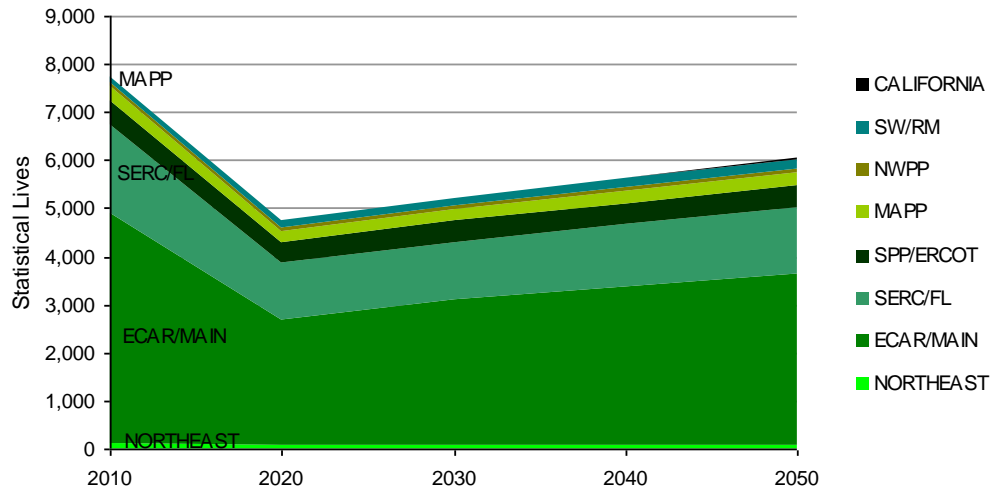
### 3.3. Human Health Benefits of the Transition Scenario

We estimate that that the implementation of the Transport Rule saves approximately 3,600 statistical lives annually by 2020 (out of 7,700 premature deaths in 2008). However, new requirements for coal plants in the Reference Case reduces this benefit to 3,000 statistical lives saved through the Transport Rule. In the Transition Scenario, retiring the most costly (and often dirtiest) plants first, as well as implementing the Transport Rule, saves 4,200 statistical lives annually by 2020.

By 2050, the Transport Rule has run its course, and new plants in the Reference case have increased premature mortalities back to 5,300 per year. In contrast, all remaining plants have retired in the Transition Scenario, saving those 5,300 statistical lives.

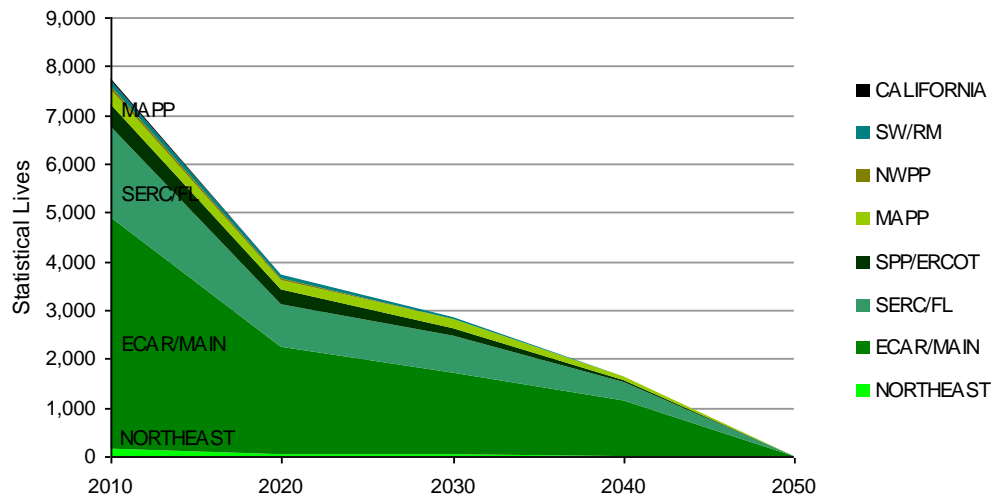
**Figures 6 and 7** show the trajectory of these two scenarios, respectively.

**Premature Mortality (Statistical Lives per Year)  
CSI Reference Case**



**Figure 6. Premature mortality in the CSI Reference Case**

**Premature Mortality (Statistical Lives per Year)  
CSI Transition Scenario**



**Figure 7. Premature mortality in the CSI Transition Scenario**

The curved shape of the decline in premature mortality in the Transition Scenario is based on two factors:

- mandatory emissions controls applied to a large number of plants between 2010 and 2020 following the EPA’s Transport Rule, and

- the retirement of the least economic, and often dirtiest, coal plants first<sup>22</sup>
- the most economic plants are often already controlled, with lower emissions rates and are therefore responsible for fewer premature mortalities; these units comprise the 2040 to 2050 block of retirements.

### 3.4. Value of Health Benefits Relative to the Reference Case

#### *Value of a Statistical Life*

In this research, we are only able to definitively monetize the value of human life, and in this case, only because we have distinct guidance from the US EPA, other federal agencies, and the National Research Council (NRC). The US EPA is charged to “protect human health and ... safeguard the natural environment”,<sup>23</sup> however, in some circumstances, Presidential Executive Orders have required a cost-benefit analysis in evaluating the efficacy of environmental regulations. To comply with these mandates, the EPA has applied a median estimate for the Value of a Statistical Life (VSL). The VSL represents the aggregate value of reducing risks across a large population, based on that population’s willingness-to-pay (WTP) to reduce their own risk. If an individual knew that they could mitigate their own risk of death for a one-in-a-million risk, their willingness-to-pay (e.g. \$5 to mitigate the 1:1,000,000 risk) multiplied throughout the population (1,000,000 individuals) would result in an estimated VSL (in this example, \$5,000,000 per statistical life).

There are three basic mechanisms for deriving VSL:<sup>24</sup>

- **Compensating wage analysis:** the wage premium demanded by a worker engaged in high risk employment is used to infer how much workers have to be compensated to take higher risks;
- **Consumer behavior studies:** consumer choices which have particular risks (such as not wearing a seatbelt) and value to a consumer (the time required to buckle a seatbelt) are divided by the reduction in risk by not engaging in the behavior (i.e. the risk of not dying if a seatbelt is worn);
- **Contingent valuation:** detailed, information-rich surveys are taken of the public, spelling out specific risks and evaluating individual’s willingness-to-pay to reduce that risk.

These surveys and studies reveal a wide range of VSL, ranging (in 1998\$) from under \$1 million to over \$10 million.<sup>25, 26</sup> Based on these values, the EPA chose a median

<sup>22</sup> In the period between 2010 and 2020, the first coal plants being retired are *not* subject to the Clean Air Transport Rule, and thus have a higher than average emissions rate and higher than average damages on a per unit energy basis.

<sup>23</sup> EPA, 2010. <http://www.epa.gov>

<sup>24</sup> Alberini, A. 2005. Robustness of VSL Values from Contingent Valuation Surveys. Working Paper #05-01. National Center for Environmental Economics

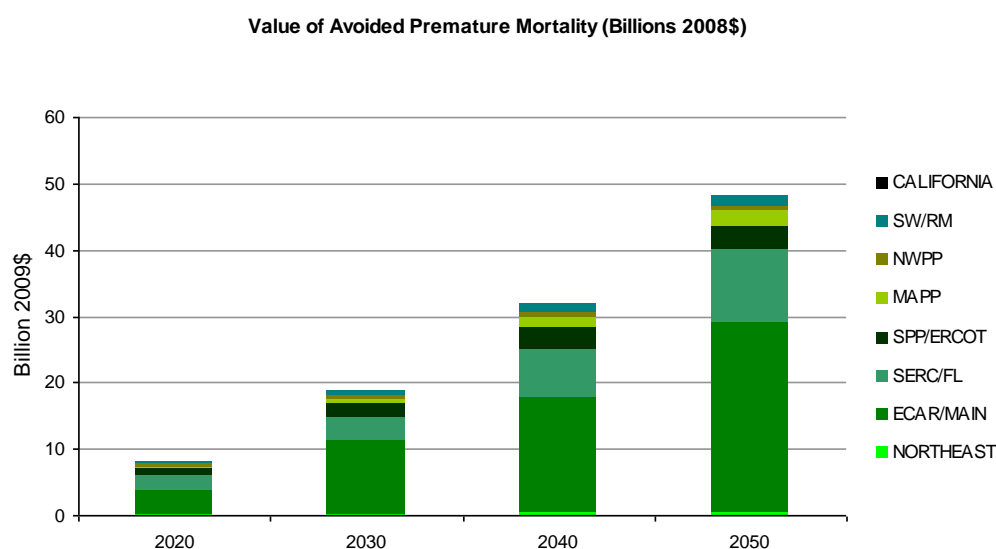
<sup>25</sup> JR Mrozek, LO Taylor. 2002. What Determines the Value of Life? A Meta-Analysis. *Journal of Policy Analysis and Management* 21(2):253-270

value of \$5.5 million in \$1999 based on income levels in \$1990.<sup>27</sup> The EPA currently recommends a VSL of \$7.4 million (2006\$).<sup>28</sup> Inflated to 2009\$, this VSL is roughly \$8 million.<sup>29</sup>

### **Monetary Value of Health Benefits of the Transition Scenario**

Relative to the Reference Case, the Transition Scenario saves upwards of \$40 billion dollars per year in lost lives by 2050.

Using the EPA recommended Value of a Statistical Life (VSL) inflated to 2009\$, our VSL is approximately \$8.0 million 2008\$. **Figure 8**, below, shows the value of the avoided premature deaths in the CSI Transition Scenario relative to the Reference Case. Each dollar value is an annual benefit to society. Again, it should be noted that the benefits are not necessarily incurred in the region of generation.



**Figure 8. Benefit of Avoided Mortality in the CSI Transition Scenario relative to the Reference Case.**

As seen in the “Beyond BAU” report, much of the benefit for the Transition Scenario is derived in future years; the more aggressively coal plants are retired, the faster health benefits accrue.

It is useful to note that not all regions experience a similar impact from the existing and future coal fleet. In **Figure 9**, we see that avoided damages on a per MWh basis are far

<sup>26</sup> Viscusi, W.K., J.E.Aldy. 2003. The Value of a Statistical Life: a Critical Review of Market Estimates Throughout the World. <http://www.ppge.ufrgs.br/GIACOMO/arquivos/eco02268/viscusi-2003.pdf>  
<sup>27</sup> EPA, 2006. Regulatory Impact Analysis for the Final Clean Air Interstate Rule. Chapter 5: Benefit Analysis and Results. <http://www.epa.gov/ttnecas1/regdata/RIAs/Chapter%205--Benefits.pdf>  
<sup>28</sup> EPA, 2010. <http://yosemite.epa.gov/ee/epa/eed.nsf/pages/MortalityRiskValuation.html#agencies>  
<sup>29</sup> It should be noted that VSL are adjusted for inflation. However, research also suggests that the real dollar VSL should increase over time as willingness-to-pay increases with real income. This research has not inflated VSL over the 40 year analysis period.

higher from generators in the ECAR/MAIN region (covering the mid-Atlantic through Kentucky to Illinois) than in any other region, primarily because the generators in this region are large, downwind of very large population centers, and generally not controlled for NOx and SO2. The generators associated with California are only the Intermountain Power unit, which is stationed in sparsely populated southern Utah and sends the bulk of its power to California.

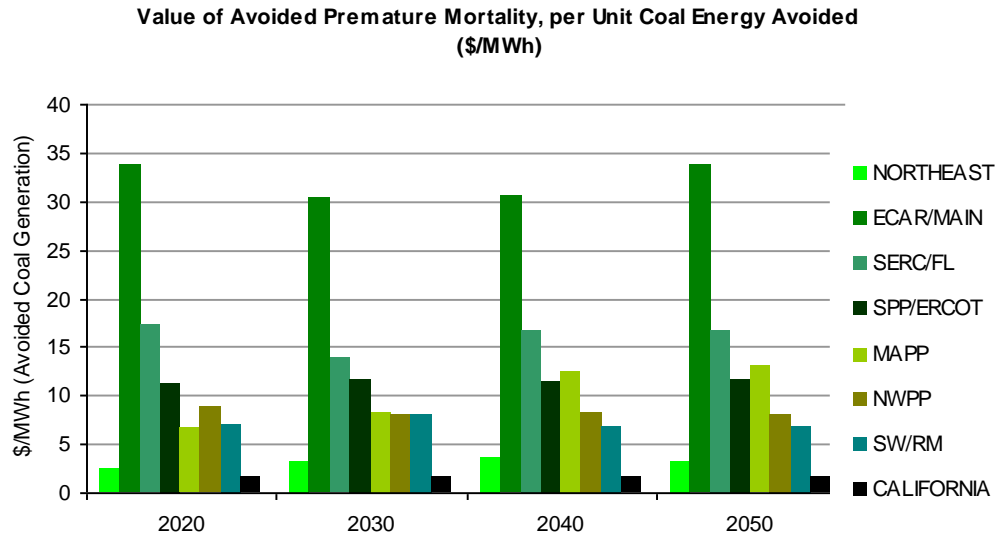


Figure 9. Benefit of avoided mortality per MWh of coal energy avoided.

The value of the avoided mortality from retiring the coal fleet incrementally through 2050 exceeds the marginal incremental costs of the Transition Scenario through most of the analysis period. The “Beyond BAU” report found that the Transition Scenario would have a net cost of approximately \$10 billion in 2020 and \$12 billion in 2030, followed by net savings of \$5 billion in 2040 and \$13 billion by 2050. If we add in just the incremental avoided costs to human health from retiring the coal fleet (see **Figure 10**), the net cost of the Transition Scenario shrinks to less than \$2 billion in 2020, and becomes a net savings by 2030. In an electric industry which saw retail sales of nearly \$346 billion in 2009, this incremental cost becomes vanishingly small.<sup>30</sup>

<sup>30</sup> US DOE, Energy Information Administration (EIA), 2010. Form 861, Utilities (2009). Retail Revenues.

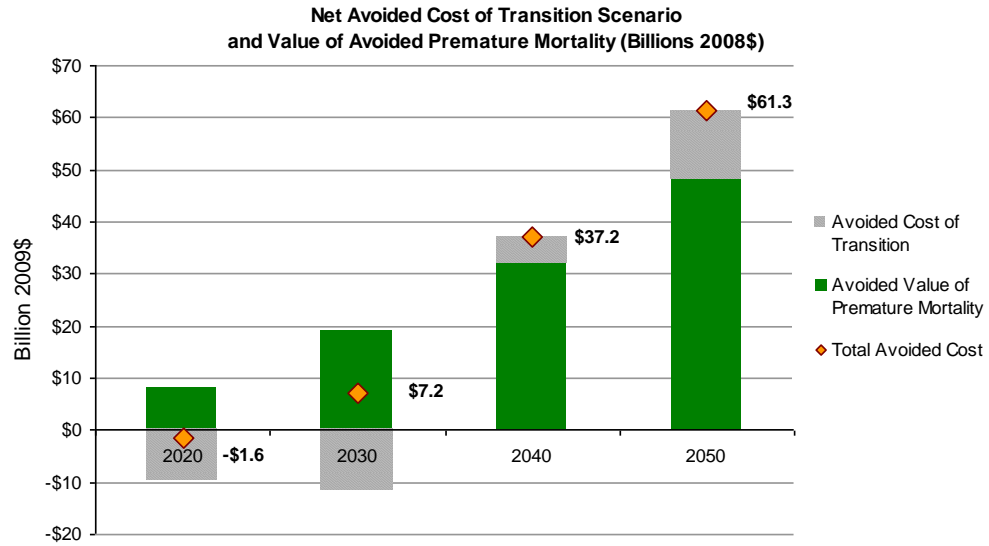


Figure 10. Net avoided cost of transition scenario with value of avoided premature mortality relative to the reference case.

If we accept that human health and life has a value to society, and that its monetization is an appropriate metric for measuring the efficacy of environmental policy, then this analysis would suggest that there is a very large net benefit to society (both monetary and monetized) for retiring the existing coal fleet.

## 4. Water Use and Consumption

### 4.1. Background: Water Use from Thermal Electric Generators

Fossil-fired and nuclear electric power generators across the United States use steam to create electricity, and these plants depend on local water bodies to provide a steady supply of cooling water. These types of power generators currently make up the bulk of the nation's fleet of electric units, and as the use of electricity increases across the country, so does the pressure on water resources. According to data collected by the United States Geographic Survey (USGS), water withdrawals from thermoelectric power sources account for 49 percent of total withdrawals in the United States in 2005. This is equivalent to more than 201 billion gallons of water per day that is used for power plant cooling alone. Total water resources must be divided between many different types of users, however, and those include agriculture, industry, and the public. **Figure 11** below, shows the current distribution of total water withdrawals among users in the United States.

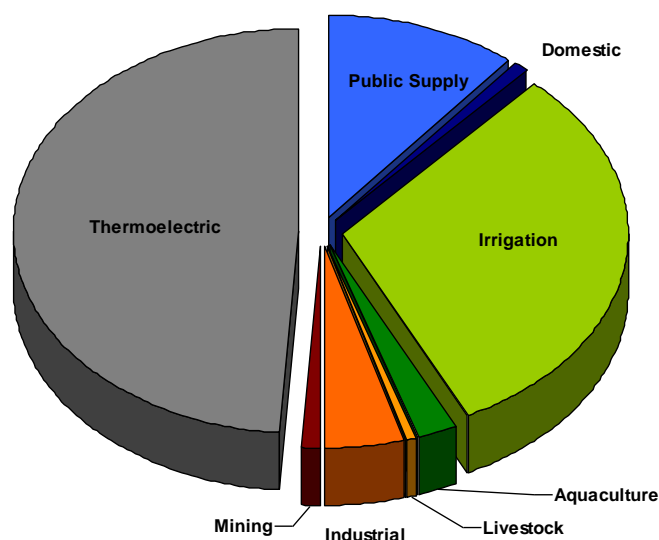


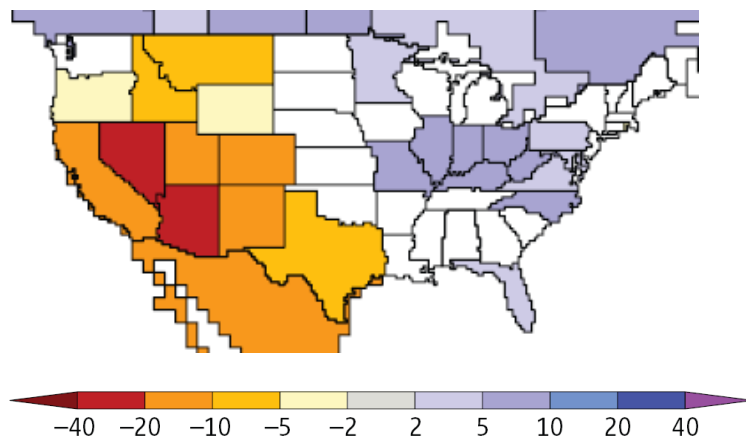
Figure 11. Fraction of total water withdrawals in the United States, by category, 2005.<sup>31</sup>

#### ***Water Scarcity, Water-Use Conflicts, and Climate Change***

Additional demands on water resources are created as population grows, and as a result, agriculture must expand, more power plants must be built to supply increasing demand for electricity, and water utilities must provide more water to meet public need. As the earth's climate changes, generally becoming hotter and drier, less water is available to meet these demands and competition for limited water resources will

<sup>31</sup> US Geological Survey. 2009. Estimated Use of Water in the United States. Circular 1344. Page 5.

increase. Impacts from climate will vary from region to region, however, and climate models show that while some regions will experience net losses in freshwater available, other regions will experience gains.<sup>32</sup> **Figure 12** shows one set of projected changes in water availability by 2050. The western United States is expected to experience declines in water availability, the Southeast and Northeast are expected to maintain a similar amount of water availability, and the Midwest and Mid-Atlantic are predicted to have a slight increase in water availability.



**Figure 12. Model predicted percentage change in water availability in the United States by 2050 relative to 1900-1970. Adopted from 33.**

Conflicts between users over limited water resources are already being observed today. One of the worst droughts on record in the state of Colorado occurred during 2002-2003, and led to the shutdown of all the major industrial water customers in the town of Pueblo, with the exception of the coal-fired Comanche Power Plant. Xcel Energy, the owners of Comanche, had contracted with the Pueblo Water Board for water rights of more than 2.6 million gallons of water to supply its wet-cooling system, at a cost of \$2.5 million per year.<sup>34</sup> This volume of water would have served approximately 70,000 people, or two-thirds of the population of Pueblo. In order to meet municipal water needs, cities were forced to purchase water rights from local farmland. Years later, Xcel proposed to build its Comanche 3 unit with a wet-cooling system, but opposition from regional and local interest groups over the proposed water use at the plant led Xcel to adopt a hybrid wet-dry cooling system, which uses 50% less water than the traditional wet system.<sup>35</sup>

<sup>32</sup> Milly, PCD., et al. February 2008. Stationarity is Dead: Whither Water Management. *Science*: 319 (1). Page 573.

<sup>33</sup> *Ibid.* Page 574.

<sup>34</sup> US DOE National Energy Technology Laboratory Power Plant-Water R&D Program. [http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/Power%20Gen%202006\\_Water%20R%26D.pdf](http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/Power%20Gen%202006_Water%20R%26D.pdf)

<sup>35</sup> Feeley, Thomas. et al. 2006. Department of Energy/National Energy Technology Laboratory's Power Plant-Water R&D Program. Page 4.



Even in regions where climate change is expected to increase water availability, increased temperatures can heat water sources such that they are too warm for use at power plants. During the summer of 2010, the Tennessee Valley Authority (TVA) was forced to cut power production at its Browns Ferry Nuclear Power Plant near Athens, Georgia because the water in the Tennessee River in Alabama was simply too hot to be used for plant cooling. The plant operated at half power for a significant portion of July and August, which caused TVA to lose approximately 1,500 MW, or \$50 million, in power generation during peak summer months when electricity generation is needed most urgently. According to TVA officials, the utility spends more than \$1 million to pay for replacement power for each day that Brown's Ferry operates at half capacity. These additional costs are passed on to ratepayers in the TVA service territory as part of the fuel cost adjustment on monthly electricity bills, which increased by more than 25 percent between March and August.<sup>36</sup>

Examples like these will only increase in number and severity as temperatures rise and water resources become scarcer. Water use at power plants is one of the externalities – or indirect social costs not transmitted through prices – of power production, and generation of electricity consumes a portion of a limited natural resource and makes it unavailable for other users. Because energy production has such a large water footprint, decisions about electric generating resources provide an opportunity to reduce the pressure that energy demands exert on water resources. This analysis evaluates the projected water footprint under the Reference Scenario and compares it to the water footprint under the Transition Scenario, where all coal-fired electric generation is phased out by the year 2050.

Generation of electricity uses water for a number of purposes – including during fuel extraction and processing, to increase efficiency of boilers, and as part of the pollution control process – power plant cooling requires the most significant volumes. The amount of water needed for cooling depends largely on the type of cooling system installed at the power plant, which use water or air to condense the steam emitted by a generating unit's steam turbines. It is important to note the difference between the water that is withdrawn by power plants, when water is taken from a source for use in cooling, and the water that is consumed by power plants, when water is evaporated and not directly available for reuse at the plant.

### ***Power Plant Cooling Systems***

Steam-driven power plants, including coal, nuclear, oil, gas, and solar-thermal powered generators use cooling systems to condense steam, creating a pressure differential which drives the generating turbine. There are a variety of mechanisms used to cool this steam, including dumping the heat directly into a water body (once-through cooling), evaporating the heat as water vapor in cooling towers, and radiating the heat directly to the air in dry-cooling structures. Alternatively, the waste heat at some power plants is

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<sup>36</sup> Flessner, Dave. August 2010. Hot River Forces Costly Cutback for TVA. Cattanooga Times Free Press. Page 1.

used to create useful steam for industrial or commercial end-uses: these “co-generating” power plants are generally operated primarily for industrial uses, and create electricity as a by-product. Co-generators are excluded from this analysis.

**Once-through cooling (OTC)**, or open-loop, cooling systems withdraw large volumes of water from a source, move it through a unit’s heat exchangers to condense the steam, and then return most of the water to the source. Because water only passes once through the heat exchangers, OTC systems withdraw significant amounts of water, but only consume about 1 to 2% of what is withdrawn.<sup>37</sup> The EPA has found that open-loop systems have detrimental effects on both water quantity and quality. The significant amount of water drawn by OTC systems (on average, an Olympic-sized swimming pool every minute for an 800 MW coal-fired plant) pins fish against exclusion screens, cooks extraordinary numbers of fish eggs, larval fish, and other small organisms, and raises the temperature of rivers, streams, lakes, and coastal waters.

OTC systems rid themselves of waste heat through flowing rivers and streams, tidal flushing in bays and estuaries, or through massive cooling ponds which can have surface areas of several square miles. The absolute amount of water consumed by OTC systems is still an open question: these plants consume very little water at the generators themselves, but by raising water temperatures and contained cooling ponds, force significant evaporation off of surfaces.

**Recirculating**, or closed-loop, wet cooling systems withdraw water from a source, move it through heat exchangers, cool the water using towers, and continue to recirculate the water. Because the water is recycled within the system, less is withdrawn from the source, but 80% or more of what is withdrawn is consumed through evaporation.<sup>38</sup> As the water evaporates, impurities and pollution in the water becomes concentrated, and the water must eventually be refreshed. This discharged water, known as “blowdown”, is of a lower quality than the withdrawn water.

**Dry-cooling** systems cool power plants without the use of water, and instead use air-cooled condensers that collect steam in small tubes, blow air across the tubes using fans, and collect the condensed water that has condensed at the end of the tube. Though dry-cooling does not require water, air-cooling requires very large cooling structures, are generally more expensive to build or retrofit at existing facilities, and can also result in a loss in efficiency at the thermoelectric plant. In high-temperature environments (where water is often short as well), dry-cooled systems can radiate heat less effectively, leading to a lower efficiency at the plant. This “de-rating” at the plant means that marginally more fuel is needed to produce one unit of electricity, which could lead to higher greenhouse gas emissions, and higher capacity requirements for the very hottest days.

**Hybrid cooling** systems, like the one mentioned above in the example of Xcel Energy’s Comanche 3 plant, use a combination of wet and dry cooling. These systems can either

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<sup>37</sup> University of Texas at Austin. April 2009. Energy-Water Nexus in Texas. Page 8.

<sup>38</sup> *Ibid.* Page 8.

employ parallel wet and dry-cooled systems, or use misted water to help cool air-cooled condensers. There are very few of these systems in operation in the US today.

### ***EPA Water Use Regulations***

The EPA is developing regulations under §316(b) of the Clean Water Act, which requires that “the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact.”<sup>39</sup>

The EPA currently requires that new electric generating units use at least closed-loop cooling systems, as opposed to once-through systems. The agency had considered a regulation that would force existing large power plants using once-through technologies to retrofit their units with closed-loop systems, but has suspended the rulemaking. The state of California, however, chose to move forward with a similar regulation on its own. California requires that existing power plants reduce intake flows at each unit to a level that is similar to that achieved by a closed-loop system, or to reduce mortality of marine life to a comparable level if a reduction in intake is not feasible.<sup>40</sup>

## **4.2. Methodology: Estimating Water Use**

While some thermal power plants report data on water use to both state and federal agencies, not all of them do so. Of those that do report data, it can often be inconsistent from year to year, and from agency to agency. The Energy Information Administration (EIA), a branch of the US Department of Energy, collects data on cooling system type, water withdrawn, and water consumed for those generating units that reports the values. Data from EIA Form 860 (2008) were used to determine cooling structure type; data from EIA Form 923 (2008) were used to estimate water withdrawals and consumption for each cooling tower, where reported. Cooling tower water use is given as the average water withdrawn, discharged, and consumed in cubic feet per second, measure fundamentally non-helpful for determining the water use efficiency of generators without connecting power generation to water use. Therefore, this analysis required a connection between power generation and water use on a generator-by-generator basis.

At steam-driven power plants, generating units are driven by boilers, which are cooled by cooling structures. However, cooling towers are often used to cool numerous boilers, and boilers may fire several generators (or a generator may be driven by more than one boiler). This analysis carried generation from each unit down to continuant boilers and cooling units, and water use up through boilers to linked generators. The result is an estimated withdrawal and consumption rate (given here as gallons per MWh in 2008).

In our database, 381 coal units (27% of the generators) did not report a cooling structure in 2008. These units were generally small and low capacity factor, only representing 2% of generation. We used satellite images in Google Earth to classify if these units had cooling cells, a cooling tower, a dry cooling rack, or water intakes and discharge to a water body (fresh or saline) or cooling pond. We created a new classification unit for

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<sup>39</sup> <http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/basic.cfm>

<sup>40</sup> California State Water Board. October 2010. Statewide Water Quality Control Policy on the Use of Coastal and Estuarine Waters for Power Plant Cooling. Page 1.

units with cooling ponds used exclusively by the coal generator.<sup>41</sup> In this process, we reclassified an additional 82 units (representing another 11% of generation).

Five hundred thirty units (37% of units, or 17% of generation) do not report water withdrawals or consumption to the EIA. For these units, we used the cooling system classification and the median water use rates for units which did report to estimate water consumption. In addition, units which reported below the 10<sup>th</sup> percentile or above the 90<sup>th</sup> percentile of withdrawals and consumption of their type were assumed to be outliers or mis-reporting, and adjusted to the median withdrawals and consumption of their type. These values are given in **Table 4**, below.

**Table 4. Median and range withdrawals and consumption for power plant cooling structure types in gallons per MWh<sup>42</sup>**

	Withdrawals (gal/MWh)			Consumption (gal/MWh)		
	Median	10% Percentile	90% Percentile	Median	10% Percentile	90% Percentile
Once through, fresh water (OF) [n=471]	48,000	49,000	28,000	60	2,600	-
Once through, saline water (OS) [n=44]	55,000	53,000	29,000	10	220	10
Recirculating with cooling pond(s) or canal(s) (RC) [n=13]	32,000	32,000	-	110	120	70
Recirculating with forced draft cooling tower(s) (RF) [n=109]	1,000	2,000	-	520	1,030	260
Recirculating with induced draft cooling tower(s) (RI) [n=118]	1,000	2,000	-	650	1,310	390
Recirculating with natural draft cooling tower(s) (RN) [n=59]	1,000	2,000	1,000	550	810	380
Cooling Pond (Synapse Classification) (CP) [n=68]	26,000	22,000	-	480	1,200	10

Withdrawal and consumption rates were then multiplied by electricity generation at the associated unit in order to determine total annual water use. Water withdrawal and consumption values were then applied to the generation mix in both the Reference Case and Transition Scenario, which resulted in total water withdrawal and consumption values, as well as values for avoided water use under the Transition Scenario.

### 4.3. Water Use Avoided Through the Transition Scenario

We estimate that the electric sector withdraws 42 *trillion* gallons of water each year – an equivalent of more than half of the water flowing through the Ohio River each year.<sup>43</sup> In fact, we estimate that generators along the Ohio River withdraw so much water that for

<sup>41</sup> The presence of a cooling pond is highly inconsistent in the EIA databases. Plants with large cooling ponds can claim a once-through system with cooling pond/canal, or “recirculating” through a cooling pond, or even a once-through use of a fresh-water resource. Maintaining a cooling pond has dissimilar characteristics to all of these classifications; but for the presence of the generator, these ponds would not exist, and the water which evaporates off their surface could otherwise be used for environmental, agricultural, or consumptive purposes. We therefore create a unique classification for these units.

<sup>42</sup> Authors calculations from EIA 860 (type), EIA 923 5a (generation), and EIA 923 Cooling Structures (consumption and withdrawals), as well as EIA 860 boiler-gen / boiler-cooling-structure; 2008 data.

<sup>43</sup> USGS, 2010. Surface Water data for USA: USGS Surface-Water Annual Statistics. <http://waterdata.usgs.gov/nwis/annual>. Annual discharge data for Ohio River at Metropolis, IL in 2008 approximately 317,000 cubic feet per second, or 75 trillion gallons per year.

every gallon which spills into the Mississippi River at Cairo, IL, one cup has passed through a generator on the banks of the Ohio River, and one tablespoon has evaporated to the atmosphere.

Under the Reference Case, water withdrawals and water consumption both increase between 2010 and 2050, and certain regions of the United States are responsible for greater withdrawal and consumption volumes. This is due in part to the distribution of thermal generators across the United States, and in part to cooling system choices that are often region-specific. **Figure 13** shows the current distribution of power plants in the United States. A significant portion of the coal-fired generating capacity is located in the Eastern US. Much of the power production infrastructure in this part of the country was established along major rivers, the Great Lakes, and along the coastline in order to both meet electricity demand and to provide plentiful cooling water to the different generating units, which utilize once-through cooling systems. Many of the states in the West, in contrast, generate a large portion of their electricity from hydroelectric units. There are fewer thermoelectric units, and many of those that do exist are located in areas where water is scarce or strictly managed, and thus typically use closed-loop cooling systems that require fewer water withdrawals.

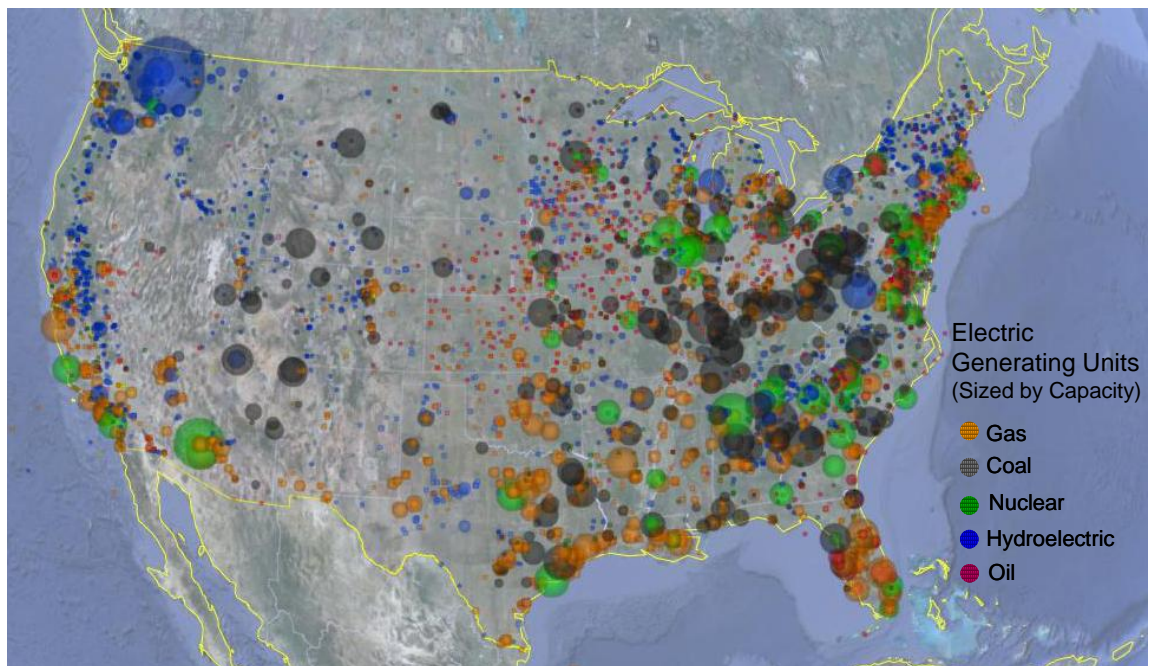


Figure 13. Distribution of US generating units in 2008, by capacity and fuel type.<sup>44,45</sup>

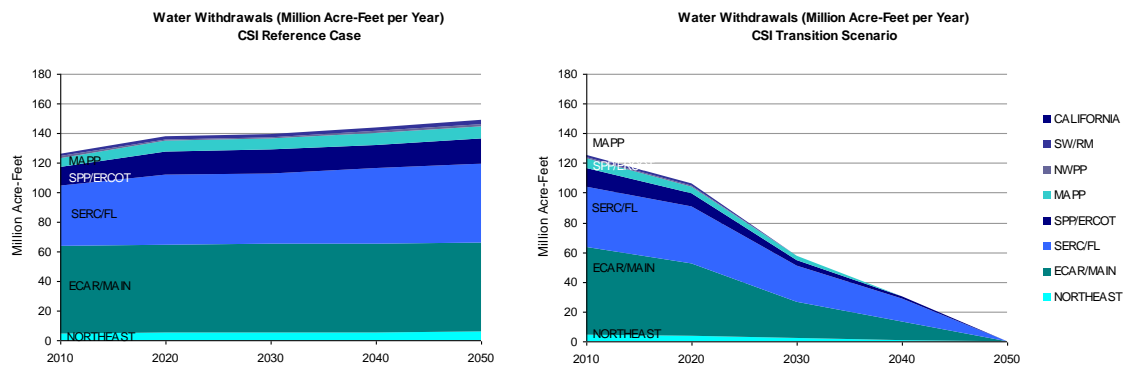
In this analysis, we refer to water use in acre-feet, a common measure for large volumes of water. An acre-foot is the volume of water which would cover a one-acre area at a depth of one foot, or about 325,000 gallons (or half the volume of an Olympic-sized

<sup>44</sup> US DOE Energy Information Administration. 2008. Form 860, and ancillary location information provided by the EIA.

<sup>45</sup> Background image Google Earth, 2010.

swimming pool). Units are given here as *millions* of acre-feet. In context, the Colorado River Compact, a 1922 agreement between eight Southwest states, allocates a total of 15 million acre-feet for industrial, agricultural, and consumption purposes. By way of contrast, the US coal fleet withdrawals over 125 million acre feet, and irrevocably consumes 2.5 million acre-feet.

While water withdrawals increase in the Reference Case with the continued operation of existing coal units and the addition of new coal units, water withdrawals decline in the Transition Scenario as existing units are retired. **Figure 14** shows the withdrawal values between 2010 and 2050 for the Reference Case and the Transition Scenario, on the left and right, respectively.

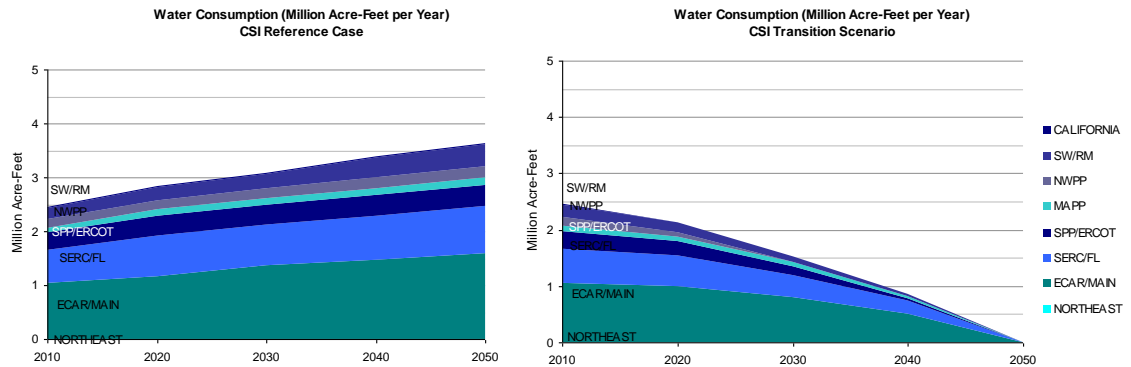


**Figure 14. Water withdrawals (thousand acre-feet per year) in the Reference Case (left) and Transition Scenario (right).**

**Figure 14** shows that, in the Reference Case, water withdrawals increase from approximately 120,000 acre-feet per year in 2010 to nearly 150,000 acre-feet per year in 2050. Withdrawals go up slightly in each of the regions shown; however, different regions have significantly different withdrawal volumes. The Northwest (NWPP) withdraws the smallest amount of water for thermal generation, while the largest volumes are withdrawn in the Southeast (SERC/FL) and the Midwest (ECAR/MAIN). Withdrawals in the Southwest (SW/RM), while small compared to other regions, more than double between 2010 and 2050.

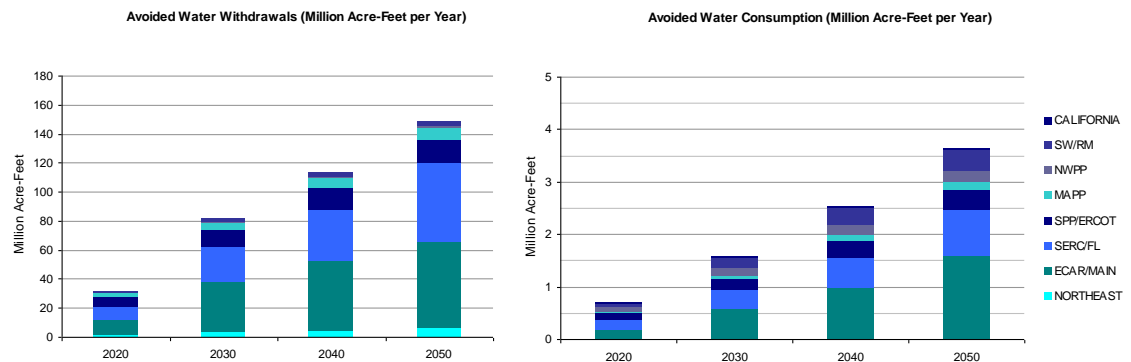
Water withdrawals under the Transition Scenario decrease in every region in every year as coal-fired generation is phased-out, but some regions experience more dramatic declines in certain years than other regions. In the ECAR/MAIN region, for example, water withdrawals drop dramatically between 2020 and 2030 as some of the least efficient power plants which use once-through cooling (often older components of the coal fleet) are taken offline. The scooped curve shape of this curve is generally due to the retirement of the once-through cooling fleet in earlier decades and the wet-cooling fleet in later years. Even though the same amount of coal generation is retired from 2030-2040 as in the earlier decade, the decline in water withdrawals is significantly less because these plants are generally higher efficiency.

Conversely, water consumption numbers in the Transition Scenario, shown in **Figure 15** below, have a convex shape. This is because once-through cooling plants, which have fairly low absolute evaporation at the plant (and hence consumption) are retired early, while newer wet-cooling plants with relatively higher consumption rates are retired in later years.



**Figure 15. Water consumption (thousand acre-feet per year) in the Reference Case (left) and Transition Scenario (right).**

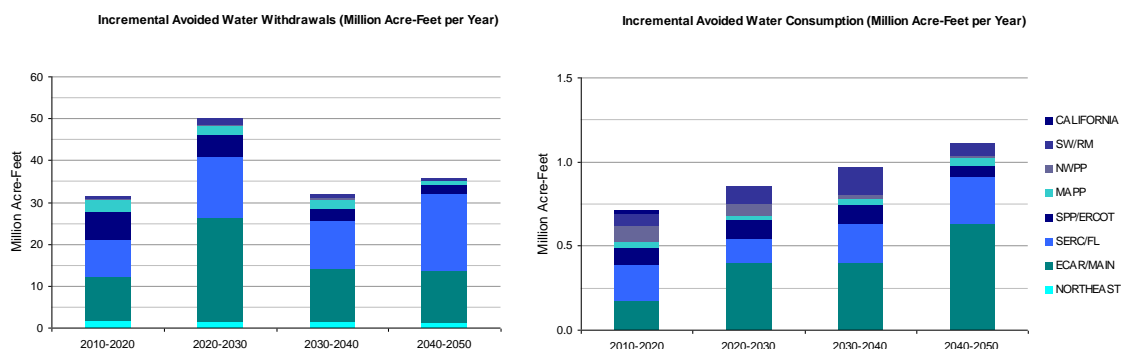
Water consumption values in the Reference Case increase from 2.5 million acre-feet per year in 2010 to nearly 3.5 million acre-feet per year in 2050 (see **Figure 15**). The biggest regional increases are again observed in the Midwest and Southeast. While smaller on an absolute scale, water consumption in the Southwest region almost doubles between 2010 and 2050, a scenario which would strain already stressed water supply in this arid region.



**Figure 16. Water withdrawals (left) and water consumption (right) avoided through the Transition Scenario.**

In retiring the least economic elements of the coal fleet, the Transition Scenario avoids withdrawing 31 million acre-feet each year within the next decade, ramping to 150 million acre-feet by 2050 (see **Figure 16**, left). The Eastern Seaboard and Midwest (In ECAR/MAIN) the rate of avoided water withdrawals is far faster in the first decades than later decades, potentially as the oldest (and least economic) elements of the fleet which

are majority OTC retire (see **Figure 17**, below, left). The story is not the same in the Southeast and Florida (SERC/FL), where some of the largest and currently most economic power plants line the waterways and coastlines, and continue withdrawing water well into 2040 in the Transition Scenario unless remediation action is taken through provisions of the Clean Water Act Section 316(b).



**Figure 17. Period incremental avoided water withdrawals (left) and water consumption (right) between the Reference Case and Transition Scenarios.**

We estimate that in the Transition Scenario, the coal fleet would very rapidly start to reduce water consumption, and accelerate in each decadal period (see **Figure 17**, above, right). The pattern of avoided water use is not the same from region-to-region, but the overall trend is towards a dramatic reduction in water used by the coal fleet.

#### 4.4. Valuing the Externality Cost of Water

Water is an important commodity, both for human use (including consumption, agriculture, and industrial processes), as well as environmental requirements (supporting aquatic habitat, maintaining sustainable groundwater levels, and flushing and replenishing nutrients). Indeed, not only the quantity, but the quality of that water, its pollution level, the life it is able to support, and our ability to access it without undue processing are all important elements of its human, social, and environmental value.

In this research, we do not specifically monetize the externality or benefit of water use (or avoided water use) by coal-fired generators. The definition of the water externality is so broad and so complex, that we would be hard-pressed to find a universally appropriate value of water across the US. However, we can describe various elements which might be considered in a valuation of water use.

At the simplest scale, where water is a scarce commodity (such as in the arid Southwest), the highest value of water might be considered its externality cost. Previous research by Synapse found an average wholesale market price for water rights in Utah at about \$600 per acre-foot, but prices as high as \$6,000 per acre-foot under some circumstances. If we consider a willingness-to-pay which has extended as high as \$6,000 per acre-foot consumed, the externality price impact on the power sector would be tremendous. However, this is a price which is really only applicable to a region under



specific circumstances of water shortage (a circumstance which is likely to intensify over the next decades). Other prices may apply in other regions.

In the Great Lakes and other inland or coastal fisheries, total water withdrawals and the associated fish kills, or the thermal effluent imposed on ecosystems and the destruction of valuable habitat might be considered appropriate external costs. For example, in 2007, Dominion Energy agreed to retrofit the Massachusetts Brayton Point Power Station with cooling towers, rather than using an OTC system with the waters of Mt. Hope Bay (at the top of Narragansett Bay). The EPA had found that the station caused undue harm on an economically important fish population, and had raised the temperature of the bay temperatures significantly. Dominion is currently installing \$600 million cooling towers. We estimate that the station currently draws 286 billion gallons of water each year, and could avoid 90% of these withdrawals with the new towers. Amortized over a 15 year life, Dominion will be pay about \$75 million dollars a year to avoid about 800,000 acre-feet of water use each year. Thus, by EPA mandate, the company has internalized the cost of water withdrawals at \$95 per acre-foot.

Similar debates and mandates are being explored in California, which has passed rules to ban coastal OTC systems, and New York, where the Indian Point power station is currently fighting a mandate to eliminate its OTC system. Similar questions through the US might allow an estimate of the social value put on water withdrawals. The public desire to see the external cost of water internalized are found in regulations which compel nuclear power stations to curtail high temperature effluent, new plants which use dry-cooling, and a widespread demand for lower impacts in the water sector.

## 5. Social Cost of Carbon

### 5.1. Background: Climate Change as an Externality

#### ***Damages from Climate Change Associated with Greenhouse Gas Emissions***

Avoiding dangerous climate-induced damages requires determining the maximum temperature increase above which impacts are anticipated to be dangerous, the atmospheric emissions concentration that is likely to lead to that temperature increase, and the emissions pathway that is likely to limit atmospheric concentrations and temperature increase to the desired levels. While uncertainty and research continue, many studies now identify a global average temperature increase of 2°C above pre-industrial levels as the temperature above which dangerous climate impacts are likely to occur.<sup>46</sup> Temperature increases greater than 2°C above pre-industrial levels are associated with multiple impacts, including sea level rise of many meters, drought, increasing hurricane intensity, stress on and possible destruction of unique ecosystems (e.g., coral reefs, the Arctic, alpine regions), and increasing risk of extreme events.<sup>47</sup>

Because of multiple uncertainties, it is difficult to define with certainty what future emissions pathway is likely to avoid exceeding a 2°C temperature increase. The IPCC's most recent Assessment Report indicates that concentrations of 445-490 ppm CO<sub>2</sub> equivalent correspond to 2 – 2.4°C increases above pre-industrial levels,<sup>48</sup> while the Stern Review proposes a long-term goal to stabilize greenhouse gases between the equivalent of 450 and 550 ppm CO<sub>2</sub>.<sup>49</sup> Recent research indicates that achieving the 2°C goal likely requires stabilizing atmospheric concentrations of CO<sub>2</sub> and other heat-trapping gases near 400 ppm CO<sub>2</sub> equivalent (CO<sub>2</sub>-eq).<sup>50</sup>

The IPCC indicates that reaching concentrations of 450-490 ppm CO<sub>2</sub>-eq requires reduction in global CO<sub>2</sub> emissions in 2050 of 50-85% below 2000 emissions levels.<sup>51</sup> The Stern Review indicates that global emissions would have to be 70% below current levels by 2050 for stabilization at 450ppm CO<sub>2</sub>-eq.<sup>52</sup> To accomplish such stabilization, the United States and other industrialized countries would have to reduce greenhouse

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<sup>46</sup> Mastrandrea, M. and Schneider, S.; Probabilistic Assessment of "Dangerous" Climate Change and Emissions Scenarios: Stakeholder Metrics and Overshoot Pathways; Chapter 27 in *Avoiding Dangerous Climate Change*; Cambridge University Press, 2006.

<sup>47</sup> Schnellhuber, 2006.

<sup>48</sup> IPCC AR4, WGIII Summary for Policy Makers, 2007. Table SPM5.

<sup>49</sup> Stern, Sir Nicholas; *Stern Review of the Economics of Climate Change*; Cambridge University Press, 2007.

<sup>50</sup> Meinshausen, M.; What Does a 2°C Target Mean for Greenhouse Gases? A Brief Analysis Based on Multi-Gas Emission Pathways and Several Climate Sensitivity Uncertainty Estimates; Chapter 28 in *Avoiding Dangerous Climate Change*; Cambridge University Press, 2006.

<sup>51</sup> IPCC AR4, WGIII Summary for Policy Makers, 2007. Table SPM5.

<sup>52</sup> Stern Review, Long Executive Summary, 2007. Page xi.

gas emissions on the order of 80 – 90% below 1990 levels, and developing countries would have to achieve reductions from their baseline trajectory as soon as possible.<sup>53</sup>

### **Damages from Climate Change**

- **Sea Level Rise:** Rising sea levels inundate dry lands and wetlands. Individuals who are forced to leave flooded areas will face infrastructure losses, lost commerce, the opportunity costs of using the land, or more complex costs such as the value of existing buffers against storm surge, reduction in fish nurseries in coastal wetlands, or lost coastal groundwater resources, much less the social unrest of displaced persons.
- **Water Shortages:** Precipitation is projected to decrease in mid-latitudes (e.g. the US) and rise slightly at higher latitudes. It is expected that arid regions will become even drier, and that there will be a marked increase in drought-impacted regions. The populations which will be exposed to drought will number in the tens to hundreds of millions.
- **Human Morbidity and Mortality:** Increasing evidence suggests that climate change may impact human health across a wide range of factors, from the increasing range of malaria, dengue, and plague, to malnutrition, water shortages leading to cholera, diarrhea, and schistosomiasis, amongst others.<sup>54</sup>
- **Human migration:** Due to sea level rise, water shortages, and spreading disease, it is expected that large populations will be forced from their homes and nations, and attempt to migrate to areas less impacted by climate change. The US, as a more resilient and less impacted nation, may bear a burden of increasing forced migration.
- **Extreme weather events:** An increase in average temperatures is expected to result in longer heat waves, more or stronger tropical cyclones, stronger storm systems, and deeper, longer droughts.
- **Ecosystem Impacts:** 20-30% of plant and animal species assessed thus far by the IPCC are likely to be at increased risk of extinction. There are projected changes in ecosystem structure and function, species interactions, and species' ranges, with expected negative consequences for biodiversity.
- **Agriculture and Forestry:** Crop productivity is expected to rise slightly at mid-high latitudes if temperature increases are moderate. Lower latitudes would see decreased crop productivity. An expected increase in droughts and floods would negatively affect crops.

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<sup>53</sup> den Elzen, M., Meinshausen, M; *Multi-Gas Emission Pathways for Meeting the EU 2°C Climate Target*; Chapter 31 in *Avoiding Dangerous Climate Change*; Cambridge University Press, 2006. Page 306.

<sup>54</sup> Khasnis, A. A. and M.D. Nettleman. 2005. Global Warming and Infectious Disease. *Archives of Medical Research*. 36:689-696

## 5.2. Value of Avoided CO<sub>2</sub> Emissions

The social cost of carbon is the effort to estimate the monetary value of reducing emissions and avoiding the associated damages of climate change. There are two methods used to determine the SCC: damage costing and marginal abatement cost.

### ***Damage Costing***

The damage-based studies estimate all of the significant damages from climate change, attach economic values to them, and then aggregate them over all of the countries and over long periods of time. There are various methods available for monetizing environmental externalities such as air pollution from power plants. These include various “damage costing” approaches that seek to value the damages associated with a particular externality, and various “control cost” approaches that seek to quantify the marginal cost of controlling a particular pollutant (thus internalizing a portion or all of the externality).

The “damage costing” methods generally rely on travel costs, hedonic pricing, and contingent valuation techniques to value non-market impacts or damages. These are forms of “implied” valuation, asking complex and hypothetical survey questions, or extrapolating from observed behavior. To monetize the avoided damages from GHG emissions, economists make significant assumptions to deal with tremendous uncertainties and value judgments.<sup>55</sup> This results in a large range of values, and leads the IPCC to conclude that “The large ranges of SCC are due in the large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses, and discount rates...It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time.”<sup>56</sup>

### ***Marginal Abatement Cost***

The other approach for assigning a monetary value to CO<sub>2</sub> emissions is to estimate the marginal cost of achieving a given emissions target through emissions abatement. The marginal abatement cost approach requires identifying an emissions reduction target. In this case, we rely on current scientific understanding of the level of atmospheric greenhouse gas concentration (and the associated emissions level) that could avoid the most dangerous climate change impacts. It is then necessary to estimate the marginal cost of achieving that target through emissions abatement.

The “emissions target” approach relies on the assumption that the nations of the world will not tolerate unlimited damages. It also relies partly on an expectation that policy

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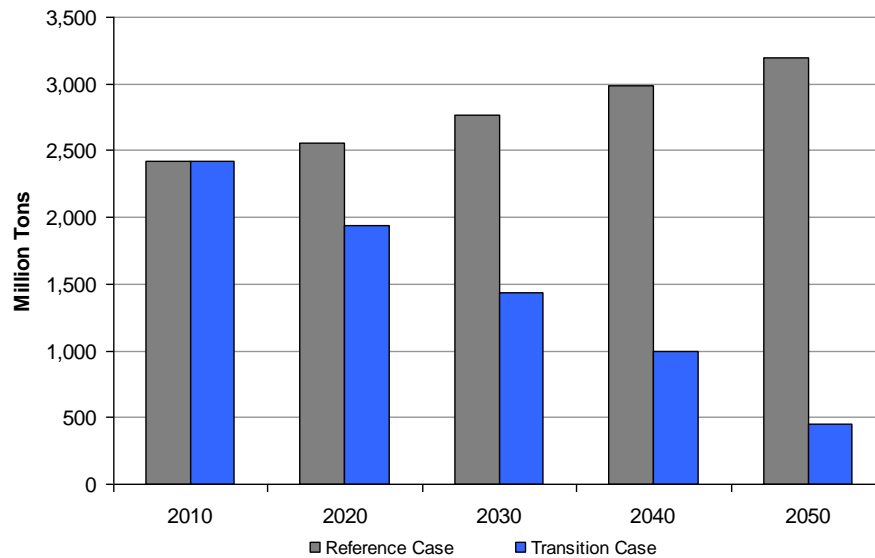
<sup>55</sup> A detailed discussion of this issue is found in Ackerman, F. *Can We Afford the Future?: The Economics of a Warming World*. Zed Books, 2009.

<sup>56</sup> IPCC. *Summary for Policymakers in “IPCC Fourth Assessment Report: Working Group II Report Impacts, Adaptation and Vulnerability”*. 2007. Page 17.

leaders will realize that emission reduction will be cheaper now than the cost of addressing climate change at a future date.<sup>57</sup> It is worth noting that, in theory, a cost estimate based on an emissions target will likely be a bit lower than a comprehensive damage cost estimate because the choice of a target reflects an assessment of the relative costs of damages and costs that will be incurred to avoid those damages.

### 5.3. Avoided CO<sub>2</sub> Emissions in the Transition Scenario

The Transition Scenario reduces the US electric sector CO<sub>2</sub> footprint by 80% by 2050 (see **Figure 18**), in line with the Administration’s current reduction goals and consistent with reaching an atmospheric burden of CO<sub>2</sub> judged to pose the least risk to society today. In contrast, the business-as-usual scenario increases carbon emissions from the electric sector by over 25% by 2050, committing the US (and the rest of the world) to much higher carbon risk.



**Figure 18. Electric Sector CO<sub>2</sub> emissions in the Reference Case**

In each year that carbon emissions increase, the goal of reducing climate change risk becomes more distant and more difficult to achieve. The atmospheric burden of CO<sub>2</sub> is cumulative, and each ton of emissions moves us closer to irrevocable damage over the next centuries. While the damages from CO<sub>2</sub> may seem a distant problem, if they are not

<sup>57</sup> A more thorough examination of this issue has been presented in the Stern Review. (Stern, N.H. et al. 2006. *Stern Review: The Economics of Climate Change*. Cambridge University Press, Cambridge). A detailed introduction of strategies to address the idea of stabilizing atmospheric concentrations of carbon dioxide can be found in Socolow and Pacala, “Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies.” *Science* (vol. 305) August 13, 2004 (pp. 968-72).

considered as a valid and solvable problem today, then we are committed to accepting the consequences in the near future.

We have not valued the social cost of carbon in this research. Other economists have spent significant effort in compiling estimated global damages, costing those damages, and the risk that those damages will occur in the future. The challenge in these studies is significant: even if we correctly predict the range of primary damages which might occur from global climate change, how do we value lives today and in the future, much less in other parts of the world? What sort of cost is associated with forced migration or international conflicts over limited water supplies? Is there a monetary value for species diversity or stable ecosystems? Are we willing to discount the cost of damages over our children and grandchildren's generation? As such, rather than monetizing the social cost of carbon, there may be more value in evaluating the consequences of climate change, and finding if we are willing to face those consequences or impose them on future generations.

## 6. Toxic Wastes from Coal Ash

### 6.1. Background: Toxic Coal Ash and Wastes

#### *Catastrophic Failure at the TVA Kingston Plant*

In December 2008, the impoundment pond holding the coal ash slurry from Tennessee Valley Authority's Kingston Plant failed and released one billion gallons of sludge. The coal ash covered over 300 acres and destroyed three homes in its path before spilling into the Emory River, a tributary of the Tennessee River. The spill immediately raised concerns over the toxic metals known to exist in coal ash.

The final TVA public health assessment released in September 2010 found the Kingston coal ash to have aluminum, arsenic, barium, cadmium, and iron in concentrations that were higher than soil in the area.<sup>58</sup> TVA and the Tennessee Department of Environment and Conservation issued an advisory for the use of the Emory River following the spill, which was patrolled by the Army Corps and the Coast Guard for another five months. While early tests suggest that local groundwater and drinking water sources were not immediately impacted, some environmental groups found increased levels of selenium, barium, cadmium, and lead in soil tests.<sup>59</sup>

#### *Coal Ash Toxicity*

Coal contains trace levels of many metals, which become more concentrated when they are left behind in coal ash after the burning process. The elements present in coal ash are: arsenic, barium, beryllium, boron, cadmium, chromium, thallium, selenium, molybdenum, and mercury.

Metals found in coal ash are toxic and carcinogenic: inhalation or ingestion of these compounds are linked with a number of health issues, both chronic and acute.

- **Selenium** exposure can lead to selenosis in humans resulting in lung, liver, and neural damage, and is highly toxic to fish;
- **Barium** (in a soluble form) interferes with neuron function, and can lead to tremors, weakness, and paralysis;
- **Cadmium** poisoning causes brittle bones and kidney failure;
- **Lead** impacts most organs, but is particularly pronounced as a neural toxin, causing developmental delays and brain damage in children;
- **Arsenic**, is a pronounced carcinogen and has been linked with cancers of the lung, bladder, and skin.

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<sup>58</sup> Tennessee Valley Authority. 2010. Public Health Assessment. Final Release. Available online: [http://health.state.tn.us/Environmental/PDFs/pha-e-TVA\\_Kingston\\_Fossil\\_Plant\\_Final.pdf](http://health.state.tn.us/Environmental/PDFs/pha-e-TVA_Kingston_Fossil_Plant_Final.pdf)

<sup>59</sup> Newsweek. 2009. Toxic Tsunami. Available online: <http://www.newsweek.com/2009/07/17/toxic-tsunami.html>

In the environment, heavy metals (such as those found in coal ash) bio-accumulate. These compounds are taken up by plants, including food crops, and are subsequently eaten by animals, fish, and us. Humans can be exposed to metals from coal ash and combustion products through contaminated groundwater, high concentrations in soils, and direct exposure to dust or ash through inhalation.

The presence of these metals means that coal ash should not be stored where rainwater can leach the metals into aquifers and groundwater. However, it is estimated that nearly two-thirds of surface impoundments lack liners to prevent leaching, and over half of these have no monitoring system to determine if they are leaking metals. Approximately one-third of all impoundments were not designed by an engineer.<sup>60</sup>

### ***Exposure to Coal Ash and Wastes***

The EPA examined the risks of coal ash in 2007, and found 584 coal ash disposal sites around the country.<sup>61</sup> The EPA report identified increased risk to one-in-fifty of getting cancer from living near unlined ponds that result in water polluted with arsenic, as well as an increased risk of vital organ damage from heightened levels of cadmium and cobalt. The report found sixty-seven sites in twenty-three states where coal combustion products (CCPs) had contaminated the water. Twenty three of these sites are known to have caused off-site contamination.

In February 2010, the Environmental Integrity Project and Earth Justice published a paper building on the 2007 EPA report.<sup>62</sup> These organizations found an additional 31 sites contaminated by coal ash. The data showed acute problems with pollution from arsenic, selenium, lead, sulfates, boron, mercury, and cadmium. Nineteen of the thirty-one sites had extremely elevated levels of arsenic, with one waste site reporting onsite groundwater arsenic in concentrations 145 times the federally permissible level. Some examples of the consequences of contamination sited in the report are:

- a boron and sulfated contaminated water supply that had to be abandoned in Montana,
- arsenic contamination leading to a bay on Lake Huron being labeled an “International Area of Concern”,
- mercury in residential wells in Tennessee, and
- selenium in surface waters four to five times the federally permitted level in West Virginia.

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<sup>60</sup> Michigan Messenger. 2010. EPA holds first public hearing on coal ash regulation. <http://michiganmessenger.com/41464/epa-holds-first-public-hearing-on-coal-ash-regulation>. Accessed November, 2010.

<sup>61</sup> US EPA. 2007. Human and Ecological Risk Assessment of Coal Combustion Wastes. Draft. Available at: <http://www.earthjustice.org/sites/default/files/library/reports/epa-coal-combustion-waste-risk-assessment.pdf>

<sup>62</sup> Environmental Integrity Project and Earthjustice. 2010. Out of Control: Mounting Damages from Coal Ash Waste Sites. Available at: [http://www.environmentalintegrity.org/news\\_reports/documents/OutofControl-MountingDamagesFromCoalAshWasteSites.pdf](http://www.environmentalintegrity.org/news_reports/documents/OutofControl-MountingDamagesFromCoalAshWasteSites.pdf)



In August 2010, the Environmental Integrity Project and Earth Justice put out an additional report that added thirty-nine new contaminated sites. Including the EPA's 2007 results, the new total was 137 sites in thirty-four states. Thirty-five sites had groundwater monitoring wells, and all of those showed concentrations of heavy metals that exceeded federal standards. Additionally, eighteen of the sites are within five miles of a public groundwater well.<sup>63</sup>

### ***Managing Coal Wastes***

In June 2009, the EPA released a report that found that out of 431 units managing slurried coal wastes, forty-nine (at thirty different locations) have a "high hazard potential" rating, defined as "a failure will probably cause loss of human life; the rating is not an indication of the structural integrity of the unit or the possibility that a failure will occur in the future."<sup>64</sup>

In May 2010, the EPA proposed new approaches to regulate the disposal and use of CCPs. The last time CCPs were examined for their risks was in 2000, when, after significant lobbying, the EPA ruled that CCPs would be regulated as non-toxic wastes.<sup>65</sup> The new rule proposal has two options – to regulate CCPs as special wastes under the hazardous waste provisions of Subtitle C of the Resource Conservation and Recovery Act (RCRA), or to regulate CCPs under the non-hazardous waste provisions of Subtitle D of the RCRA.<sup>66</sup>

## **6.2. Methodology: Estimating Coal Ash Waste Production**

The environmental damage which could be attributed to coal ash waste has the potential to be very significant. The coal ash disaster at the TVA Kingston Plant, subsequent outcry, and pending draft regulations to handle coal ash and wastes are all indicators that the public recognizes the danger of non-remediated coal ash, and hence the externality of coal ash exposure. We can begin to quantify the amount of coal ash which is produced in the US, but monetizing the externality of the coal ash is currently undefined, and beyond the scope of this work. At the close of this chapter, we propose methods to potentially monetize this externality, but for the purposes of this research, we quantify the amount of waste produced in the US in the Reference Case and Transition Scenarios.

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<sup>63</sup> Environmental Integrity Project, Earthjustice, and Sierra Club. August, 2010. In Harm's Way: Lack of Federal Coal Ash Regulations Endangers Americans and Their Environment. [http://www.environmentalintegrity.org/news\\_reports/documents/INHARMSWAY\\_FINAL3.pdf](http://www.environmentalintegrity.org/news_reports/documents/INHARMSWAY_FINAL3.pdf)

<sup>64</sup> US EPA. Fact Sheet: Coal Combustion Residuals (CCR) Surface Impoundments with High Hazard Potential Ratings. <http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccrs/fs/national.pdf>. Accessed January, 2011.

<sup>65</sup> Federal Register. 40 CFR Part 261. Regulatory Determination on Wastes from the Combustion of Fossil Fuels; Final Rule.

<sup>66</sup> Vinson-Elkins, 2010. EPA Proposes to Regulation Coal Combustion Residuals. <http://www.vinson-elkins.com/resources/RegulateCoalCombustionResiduals.aspx>. Accessed November, 2010.

Coal ash is a byproduct of coal combustion that is comprised of fly ash, bottom ash, boiler slag, and FGD material.<sup>67</sup> These products are often called coal combustion products (CCPs) or coal combustion residues (CCRs).

- **Fly ash** is a product of burning coal; it is a fine, powdery material composed mostly of silica that escapes via smokestacks without controls. It is removed from plant exhaust gases through electrostatic precipitators, baghouses, and scrubber systems.
- **Bottom ash** is agglomerated ash particles that are too large to be carried in the flue gases. Bottom ash is much coarser than fly ash.
- **Boiler slag** is bottom ash that is molten and then quenched with water. This causes hardening and fracturing for a hard, shiny, black product.
- **FGD material** is the product of the process used for reducing sulfur dioxide emissions. The material varies from a wet sludge to a dry powder.

Each year, electric generating units in the United States produce 134 million short tons of coal combustion products.<sup>68</sup> Coal ash is the second largest industrial stream of waste in the US, following mine waste. In comparison, Americans generated 250 million tons of municipal waste in 2008, and approximately 135 million tons were discarded in landfills.<sup>69</sup> Coal ash that is not recycled is stored in silos, landfills, or surface impoundments. In the impoundments, the CCPs are mixed in water slurry to reduce fugitive dust.<sup>70</sup>

### ***Use of Coal Wastes***

According to the EIA, approximately 32% of coal combustion products were reused or sold in 2008.<sup>71</sup> The remaining CCPs were landfilled or stored (an unclear fate, suggesting temporary disposal). The useful fraction of CCPs are used for cement and concrete production, road base, structural fill, snow and ice control, roofing granules, mining applications, agriculture, and gypsum panel products. Fly ash is mainly used for cement production, and the use of fly ash doesn't require kilning like traditional cement.<sup>72</sup> The EPA created a partnership with the coal ash industry, entitled the Coal Combustion Products Partnership, that works to increase the amount of coal ash recycled. However, this partnership has been put on hold as of 2010, while the EPA debates a proposed federal rule on the disposal of coal ash. Additionally, the partnership

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<sup>67</sup> US EPA. Coal Combustion Residuals. <http://www.epa.gov/osw/nonhaz/industrial/special/fossil/coalashletter.htm>. Accessed November, 2010.

<sup>68</sup> US DOE. 2008. Energy Information Administration. Form 923, Schedule 8, Part A.

<sup>69</sup> US EPA. 2009. Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Table 1 and 29. <http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2008data.pdf>

<sup>70</sup> <http://michiganmessenger.com/41464/epa-holds-first-public-hearing-on-coal-ash-regulation>

<sup>71</sup> US DOE. 2008. Energy Information Administration. Form 923, Schedule 8, Part A.

<sup>72</sup> American Coal Ash Association Educational Foundation. Coal Ash Facts. Accessed November, 2010. <http://www.coalashfacts.org/>

has been heavily criticized for promoting the reuse of coal ash while withholding information on the risks involved.<sup>73</sup>

This research does not seek to estimate the amount of CCPs which would be used for productive purposes in the future, or the impact of taking those products out of circulation in the Transition Scenario. These “positive” externalities should be considered in a full cost accounting externality monetization for coal ash, not provided here.

### ***Estimating Coal Waste Generation***

The EIA collects information about coal combustion byproducts and FGD byproducts from coal-fired generators in the US.<sup>74</sup> Of the coal units in this analysis, 75% (representing 98% of generation) reported the amount of coal combustion waste generated in 2008, and 19% (representing 40% of generation) reported FGD waste.

Units report generating from 60 to 260 lbs of waste for each MWh produced (10<sup>th</sup> and 90<sup>th</sup> percentile, respectively) with an average rate of 135 lbs per MWh. FGD units produce from 11 to 170 lbs per MWh (10<sup>th</sup> and 90<sup>th</sup> percentile), with an average rate of 73 lbs/MWh. Some of this variation may be due to the output efficiency of the unit, the type of coal burned, and the degree to which the FGD unit is utilized.

For the fraction of units which did not report coal combustion waste generation, we assumed the average rate of creation (135 lbs/MWh). For units equipped with FGD but not reporting FGD waste, we associated the average rate of FGD waste (73 lbs/MWh). In both the Reference Case and Transition Scenario, as new FGD units are built on existing units, we assign FGD waste to those new units.

## **6.3. Coal Ash and Waste Avoided through the Transition Scenario**

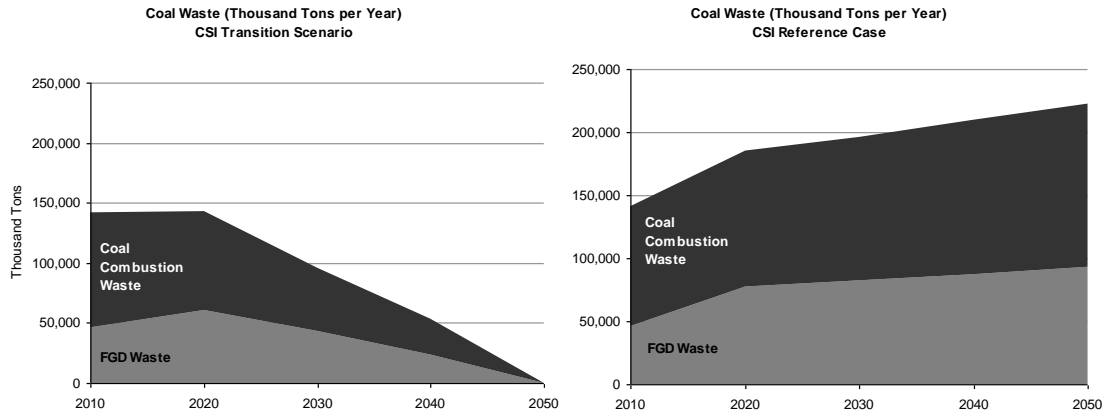
We estimate that the US produced about 96 million tons of coal combustion waste and 46 million tons of FGD waste in 2008.

It is assumed that most coal units without FGD will be required to install them under amendments to the Clean Air Act. Because of this, FGD waste products are expected to increase. In the Reference Case FGD waste rises by almost 60% to 77 million tons, and coal combustion waste rises to 108 million tons (see **Figure 19**). In the Transition scenario, coal units that do not retire before 2020 are also required to install FGD, accounting for an increase in FGD waste to 61 million tons.

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<sup>73</sup> Miami Herald, October, 2010. EPA faulted for not disclosing coal ash’s recycling risks. <http://www.miamiherald.com/2010/10/15/1875548/epa-faulted-for-not-disclosing.html>. Accessed November, 2010.

<sup>74</sup> US DOE. 2008. Energy Information Administration. Form 923, Schedule 8, Part A.



**Figure 19. Coal combustion and FGD wastes in the Reference Case (left) and Transition Scenario (right), in thousands of tons per year.**

Because many coal units do retire in this time period in the Transition Scenario, coal combustion waste decreases to 80 million tons per year for no net change in total waste from 2010 to 2020. As existing units are retired, the coal waste creation rate declines rapidly towards zero from 2020 to 2050 (see **Figure 19**). In the Reference case, coal wastes increase markedly with new FGD requirements in 2020, and then rise with new coal units coming online through 2050.

The waste avoided through the Transition Scenario relative to the Reference Case is given in **Figure 20**, below. However, it is important to note that while the production rate of coal waste declines to zero by 2050, and nearly 250 million tons of waste are avoided each year, the previously produced coal waste will still linger in landfills and containment pounds.

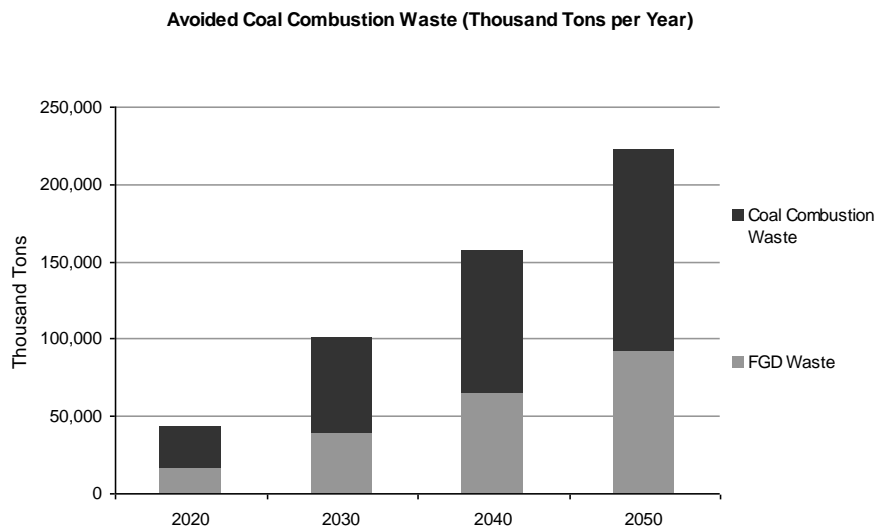


Figure 20. Coal ash and FGD wastes (in thousand tons per year) avoided through the Transition Scenario.

## 6.4. Valuing the Coal Ash Externality

In this analysis, we do not attempt to attach a monetary value to the creation or disposal of coal ash. However, there is clear evidence that such a value should exist and is real. There is a strong public desire to limit exposure to both catastrophic coal sludge spills, as well as groundwater contamination.

We can begin to estimate a first-order externality cost from the marginal cost of cleanup in the TVA Kingston spill. The cleanup is an EPA (therefore public) mandate response to a catastrophic event. The cleanup costs are expected to exceed \$1.2 billion to remediate 2.5 million cubic yards of coal ash (of 5.4 million released in the spill). If we assume that coal ash has a density of approximately 0.84 tons per cubic yard,<sup>75</sup> the cleanup will cost about \$570 per ton of ash. This is one element of a cost for a catastrophic event; and would have to be balanced by the future risk of such an event occurring again.

Alternatively, we could look at the marginal cost of abatement: to avoid another disaster similar to the Kingston spill, the TVA has indicated that it will spend between \$1.5 to \$2.0 billion dollars converting its coal ash ponds to dry storage by 2019; determining the volume of waste which would be remediated in this effort would yield an estimated externality cost from the marginal abatement cost.

It is expected that the EPA will soon propose new rules requiring coal ash pond remediation throughout the US; the value of this rule divided by the volume of coal ash remediated would yield an estimated externality value. If this ruling is promulgated, however, the incremental costs of complying with the rule could be considered an avoidable cost of not operating coal plants in the future.

Finally, a value for the externality cost of coal ash could be determined from the actual harm imposed by the coal ash, including the risk of soil, water, and air contamination, the health and environmental damages caused from such releases, and the value of the lives cut short from toxic poisoning or cancer, and the monetary value of the environmental damages caused. This mechanism for arriving at an externality cost is fraught with challenges, but would provide an estimate of the public damages imposed by coal ash.

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<sup>75</sup> Israeli National Coal Ash Board. 2010. "The Grey Resource" <http://www.coal-ash.co.il/english/>. Assumes coal ash has a density of approximately 1 [metric] ton per cubic meter = 0.84 short tons per cubic yard.

## 7. Haze and Visibility

### 7.1. Background: Regional Haze

Poor visibility can turn a visit to the Grand Canyon or other vistas into underwhelming views of vague, gray outlines (see **Figure 21**). Haze plagues public lands and the grand, iconic National Parks throughout the US. Visitors who have traveled hundreds or thousands of miles to see the Sierra Nevada Mountains, the Cascades, Rockies, canyons of the Southwest, expansive plains and Badlands, Ozarks, Great Smoky Mountains, Appalachians, or White Mountains have a very high willingness-to-pay to experience the full breadth of the landscape.

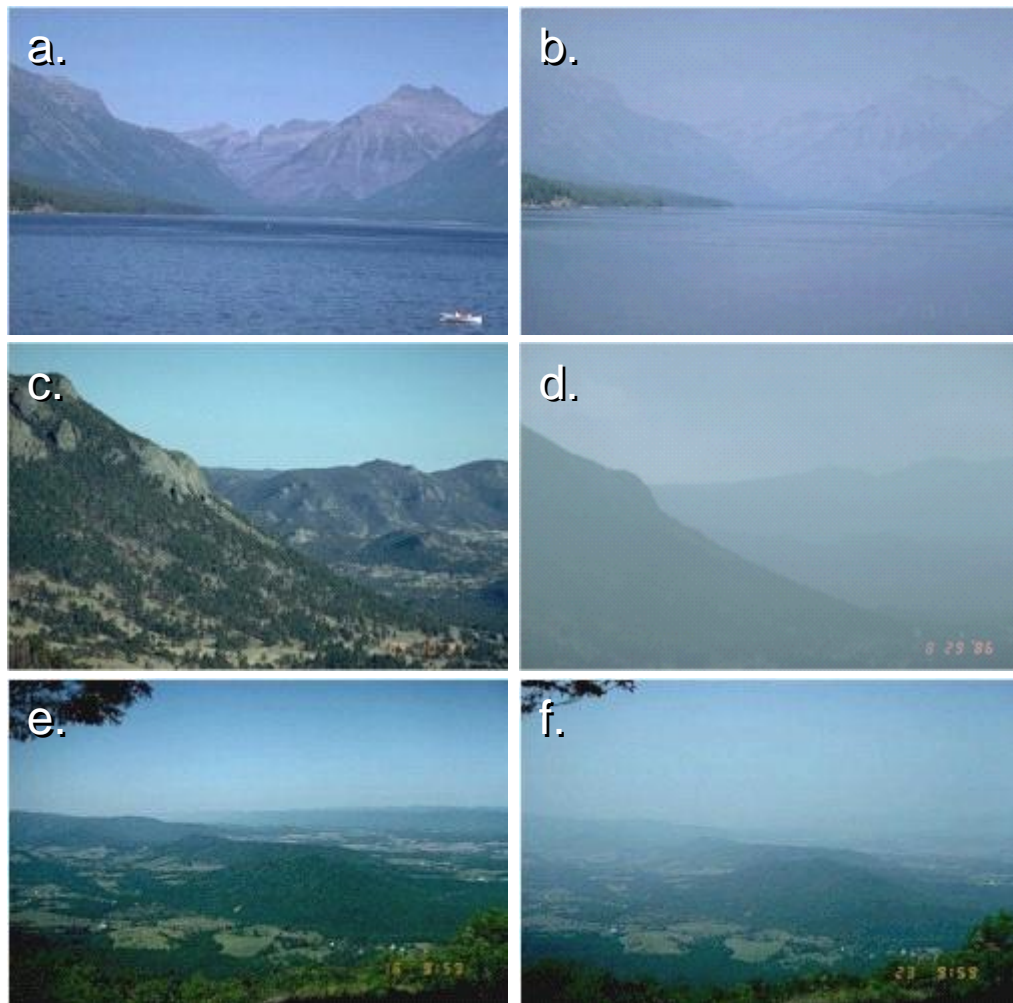


Figure 21. Visibility in three National Parks on clear days and a hazy days. (a-b) Glacier National Park; (c-d) Rocky Mountain National Park; (e-f) Shenandoah National Park. Source: EPA

Haze is not only a problem for the National Parks: poor visibility is associated with poor air quality, high ozone, and dangerous conditions for those with respiratory problems. Both the inhibited enjoyment of the landscape, as well as the strongly embedded social

perception of unhealthy conditions, and a deeply held sense of wellbeing under clear conditions render poor visibility a social cost of power generation.

Regional haze is caused by both natural and human (anthropogenic) sources. Natural sources include rain, wildfires, volcanic activity, sea mists, and wind blown dust from undisturbed desert areas. Anthropogenic sources of air pollution may include industrial processes, (electric power generation, smelters, refineries, etc.), mobile sources (cars, trucks, trains, etc.) and area sources (residential wood burning, prescribed burning, wind blown dust from disturbed soils). The economic and environmental impacts from regional haze that can be attributed to emissions from the coal-fired component of the US power-sector emissions is considered an externality of coal generation. The benefit of the Transition Scenario would be any extent that problems with visibility are mitigated, beyond any mitigation which occurs from recently enacted EPA rules, or additional proposed air quality rulings.

For the purposes of this analysis, the externality cost of regional haze attributable to the coal fleet is not characterized. While there is a base of literature examining the economic implications of good visibility in natural areas such as National Forests and Parks, the degree to which regional haze throughout the US is attributable to power generation is unclear. In addition, new rules promulgated by the US EPA strive to reduce regional haze formation at National Parks and other high-value public lands through emissions controls. If these emissions controls successfully mitigate haze concerns, the externality could be effectively internalized.

Phasing out coal from the US electric portfolio would eliminate coal's contribution to regional haze and poor visibility. While this study does not quantify the monetary benefit of improving visibility, there are significant visibility benefits to the Transition Scenario in eliminating the particulates from coal combustion.

## 7.2. Components of Regional Haze

Haze is made up of numerous small particles suspended in the air, known as aerosols. Small particles, less than 0.05 microns, interfere with visibility by scattering light in random directions. The physics of Rayleigh scattering preferentially interferes with blue light.<sup>76</sup> For example, smoke, which is made up of numerous fine particles as well as larger ash particulates, appears bluish in direct light as the particles reflect blue light back to the viewer. However, if backlit, the same smoke takes on an orange tone because the blue components of light are scattered away from the viewer.

Larger particles, up to 2.5 microns (PM<sub>2.5</sub>) scatter and refract light in many wavelengths. Smaller particles (0.1 to 1 micron), however, are closer in size to the wavelengths of visible light. Blue light bends and scatters around these small particles, giving a bluish and hazy look to front-lit landscapes (i.e. the sun behind the observer), and orange

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<sup>76</sup> Hinds, W., "Aerosol Technology Properties, Behavior, and Measurement of Airborne Particles." John Wiley & Sons, New York. 1999 (p.349)

sunrises and sunsets. The light scattering ability of different particle sizes results in the different visual appearance of haze seen by an observer.

Small particles stay suspended in the atmosphere, and thus persist for longer time periods and over longer distances than larger particles. Haze is defined on a regional basis, rather than as a state or local issue, because small particles can be transported over extremely long distances and impact visibility in remote locations, while coarser particles tend to be deposited closer to their source and are more likely to impact local conditions. Haze may be realized in at least three different forms: intrusive plumes from local smokestacks, low-lying inversion layers that are often found around urban areas, and regional haze that obscures the view in all directions. Each of these forms of visibility impairment is a function of the nature and source of emissions and the prevailing meteorological conditions.

Fine particles may contain a variety of chemical species including organic and elemental carbon, ammonium nitrate, sulfates, and soil. Each of these components can be naturally occurring or the result of human activity. The natural levels of pollutant species will result in some level of visibility impairment that, in the absence of any human influences, will vary with season, meteorology, and geography. A significant difficulty with valuing individual contributions to regional haze is that natural levels of haze vary significantly over time, and even the formation of fine aerosols from anthropogenic sources can depend on natural phenomena, such as sunlight, temperature, and volatile organic compounds (VOC) from plants.

Pollutants commonly associated with haze formation include the following:

- **Carbon** in the form of particulates or volatile organic compounds may be emitted from both stationary and mobile sources, and organic compounds in soil. Elemental, or black, carbon contributes to visibility impairment because it readily absorbs light. The contribution of absorption by elemental carbon is generally less than 10 percent of the loss in transmission radiance.<sup>77</sup>
- **Sulfur Dioxide** is especially important because it contributes to the formation of sulfates, that often dominate other causes of visibility impairment, particularly in eastern states.<sup>78</sup> Anthropogenic sources of sulfur dioxide are predominantly from electricity generation, fossil fuel combustion, and industrial processes.<sup>79</sup> Once in the atmosphere, sulfur dioxide forms sulfates, which can also lead to acidic rain.
- **Nitrogen dioxides** are found in emissions from cars, trucks and buses, power plants, and off-road equipment.<sup>80</sup> NO<sub>2</sub> gas impairs visibility, and the gas reacts with VOCs to create ground-level ozone and fine particulates.

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<sup>77</sup> Malm, W. Introduction to Visibility. Cooperative Institute for Research in the Atmosphere (CIRA), NPS Visibility Program, Colorado State University. May 1999.

<sup>78</sup> Abt Associates. Out of Sight: The Science and Economics of Visibility Impairment. Prepared for the Clean Air Task Force, August 2000.

<sup>79</sup> <http://www.epa.gov/air/emissions/so2.htm>

<sup>80</sup> <http://www.epa.gov/air/emissions/nox.htm>



### 7.3. The Social Cost of Regional Haze and Reduced Visibility

Several researchers and the US EPA have attempted to evaluate the economic impact of poor visibility in urban areas and in natural areas. In the West, there is particular interest in achieving improved air quality in parklands where visitation often depends on good visibility. Reduced visibility has an economic impact in recreation where visitation numbers may drop if expansive views are unavailable. Low visibility also implies poor air quality (and associated health consequences), and may, to some extent, drive housing prices or interest in living in areas with better air quality. Economists have developed two methods of evaluating the social cost of visibility:

- *Hedonic price analyses* in residential areas examine how housing prices vary statistically with air quality, amongst a range of other variables. Studies are typically conducted over a locality where there is a clear gradient of air quality or visibility, as well as other housing price drivers. These studies are not able to necessarily distinguish the price differential due to a preference for better visibility from a preference for healthier air quality.
- *Contingent valuation* surveys individuals with a hypothetical trade-off between fixed price commodities and less tangible values, such as visibility. Individual willingness-to-pay is determined directly from survey results.

A meta-analysis in 2002 estimated the social valuation of air quality health and visibility from a hedonistic price analysis of housing prices.<sup>81</sup> The study used compiled results from 37 studies, and, based on 1990 air quality and housing prices, estimated that the poor health and visibility cost between \$46-\$77 billion (1991\$). Citing other researchers, the study estimated that \$7-\$27 billion (1991\$), or 15-35% of this cost could be attributed to visibility concerns or aesthetics, while the remainder was due to concerns of health, soiling, or other impacts.

The social cost of regional haze has resulted in dramatic regulation aimed at internalizing the cost of haze by controlling pollution. In 1991, Congress created the Grand Canyon Visibility Transport Commission to find mechanisms to improve air quality at the Grand Canyon and nearby locations. Amongst other recommendations in the resulting 1996 report, the commission suggested preventing air pollution by monitoring and potentially regulating stationary sources, as well as promoting renewable energy and increased energy efficiency.<sup>82</sup> In 1999, the EPA promulgated the Regional Haze Rule and the Guidelines for Best Available Retrofit Technology (BART), recognizing that the burden of retrofitting high emissions sources was outweighed by the social benefit of controlling air pollution. In 2005, the EPA estimates that the rule will provide about \$309 million (2009\$) in improved visibility benefits each year, while preventing \$10.8-\$12.6

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<sup>81</sup> Delucchi, M.A., J.J. Murphy, D.R. McCubbin. 2002. The health and visibility cost of air pollution: a comparison of estimation methods. *Journal of Environmental Management*. 64:139-152.

<sup>82</sup> Report of the Grand Canyon Visibility Transport Commission to the United States Environmental Protection Agency. June 1996. Available online at <http://www.wrapair.org/WRAP/reports/GCVTCFinal.PDF>

billion of health impacts, including premature deaths. The rule is estimated to cost approximately \$1.8-\$1.9 billion annually (2009\$).<sup>83</sup>

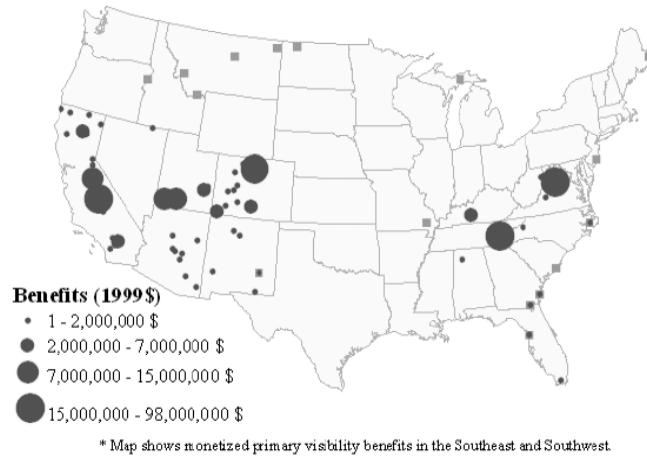
When the financial implications of the BART rule were analyzed in 2005, the EPA chose to use a contingent valuation method to estimate the recreational cost of haze.<sup>84</sup> The study estimated the demand for visibility in National Parks in California, the Southwest, and the Southeast through a survey of individuals in five states. There are a number of caveats and assumptions in this type of study related to (a) how individuals choose to characterize their own preferences versus the preferences of others, (b) the distinction (or lack thereof) between aesthetic valuation and concern for associated health impacts of poor air quality, and (c) the visibility value of the particular areas featured in the survey. Extrapolating the results of this survey to all Class 1 areas (National Parks and other high value public lands), the EPA determined that the implementation of the Clean Air Visibility Rule (CAVR) would result in benefits of \$108-\$309 million (2009\$), annually.<sup>85</sup> The map in **Figure 22** shows the distribution of some of these benefits in the Class 1 areas examined by the valuation study.

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<sup>83</sup> Fact Sheet – Final Amendments to the Regional Haze Rule and Guidelines for Best Available Retrofit Technology (BART) Determinations. Available online at [http://www.epa.gov/visibility/fs\\_2005\\_6\\_15.html](http://www.epa.gov/visibility/fs_2005_6_15.html). Dollars converted from 1999\$ to 2009\$ via US Bureau of Labor Statistics inflation estimates.

<sup>84</sup> Chestnut, L.G., and R.D. Rowe. 1990a. Preservation Values for Visibility Protection at the National Parks: Draft Final Report. Prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC and Air Quality Management Division, National Park Service, Denver, CO.

<sup>85</sup> U.S. EPA. June 2005. Regulatory Impact Analysis for the Final Clean Air Visibility Rule or the Guidelines for Best Available Retrofit Technology (BART) Determinations Under the Regional Haze Regulations. Office of Air and Radiation. EPA-452/R-05-004. Available online at: [http://www.epa.gov/visibility/pdfs/bart\\_ria\\_2005\\_6\\_15.pdf](http://www.epa.gov/visibility/pdfs/bart_ria_2005_6_15.pdf). Dollars converted from 1999\$ to 2009\$ via US Bureau of Labor Statistics inflation estimates.



**Figure 22. EPA estimated benefits of the Clean Air Visibility Rule in Class 1 areas in five states. Benefits are in 1999\$.**

In 2005, the EPA issued a Regulatory Analysis of the Clean Air Interstate Rule (CAIR), which estimated annual visibility benefits at \$1.5 billion (2009\$) by 2010, rising to \$2.3 billion by 2015.<sup>86</sup>

While the valuation of visibility is feasible, linking poor visibility and regional haze to specific emissions sources requires complex models, unavailable for this level of study. However, it is unequivocal that coal combustion contributes to regional haze throughout the US. By phasing out coal combustion and fugitive dust from coal mining, transportation, and storage operations, we eliminate the contribution of coal to regional haze, and its costs to society.

<sup>86</sup> US EPA. 2005. Regulatory Impact Analysis for the Final Clean Air Interstate Rule. Available online at <http://www.epa.gov/cair/pdfs/finaltech08.pdf>. Dollars converted from 1999\$ to 2009\$ via US Bureau of Labor Statistics inflation estimates.

## 8. Nuclear Waste and Risk

### 8.1. Background: Lingering Doubts about Nuclear Risk and Waste

The US obtains about 20% of its power from 104 active and licensed commercial nuclear reactors. These reactors, spread primarily through the eastern US and northern Midwest, were built between the 1960s and 1980s. The nuclear fleet and new nuclear power plants have been the cause of much public controversy through their operating lives, and while the focus of the objections have shifted from immediate public safety to cost, risk, and long-term sustainability, many concerns still remain.

#### *Externalities of the US Nuclear Fleet*

The public dangers of the nuclear fleet are fairly well known, but may be inadequately captured in the current market for nuclear power. The legacy of developing nuclear technology, operating the nuclear fleet for five decades, and now actively considering relicensure of half-century old plants continues to provoke serious social and environmental concerns:

- Mining and processing uranium is environmentally intensive and produces a number of dangerous waste products;
- Nuclear generation itself produces highly radioactive waste that must be secured for tens or even hundreds of thousands of years, as well as larger quantities of low-level radioactive waste that must be handled and disposed of carefully;
- Catastrophic nuclear accidents have the potential to harm large populations and render large areas of land uninhabitable for generations;
- Small leaks at nuclear plants and processing facilities pose widespread risk, and a sense of discomfort and insecurity amongst potentially exposed populations; and
- The current fleet of nuclear power plants produces wastes and byproducts which could, however crudely, be weaponized.

One reason that these concerns have stayed on the back-burner is that the frequency of catastrophic leaks or meltdowns is fairly small (although the risks and social consequences are very high), and the US public has not been exposed to the dangers of nuclear power for several decades. However, these concerns are very real, and are each rooted in precedent:

- Poor mining and milling practices from the 1940s through the early 1980s appears to have been responsible for a pronounced increased cancer rate of

millers and miners,<sup>87</sup> and ultimately resulted in the decommissioning and complete disposal of the town of Uravan, Colorado in 1986,<sup>88</sup>

- Large amounts of low level and mixed radioactive waste were improperly buried at the West Valley,<sup>89</sup> Hanford, and Savannah River<sup>90</sup> nuclear waste repositories, and are now leaking into the groundwater towards major water bodies, including Lake Erie<sup>91</sup> and the Columbia River.<sup>92</sup>
- Remediating and cleaning the Hanford Site in Washington State has become one of the world's largest cleanup efforts – work at the site cost \$12.3 billion through 2006 and is estimated to cost between \$77 and \$100 billion dollars through 2047.<sup>93</sup>
- The near meltdown at the Three Mile Island Generating station in 1979 and a critical electrical failure at Brown's Ferry in 1979 could have both resulted in a Chernobyl-type meltdown, a 1986 disaster which required the evacuation of an estimated 346,000 people from a 30 km zone around the reactor. While much of the zone surrounding the accident remain evacuated, an estimated 270,000 people still live in areas of Belarus, Russia, and the Ukraine which have radioactive contamination levels which exceed safe conditions;<sup>94</sup>
- Even today, with numerous redundant safety mechanisms in place in the US, scrams, or reactor trips due to safety or operational faults, occurred in one of every three nuclear units in 2009.<sup>95</sup> These scrams require the unit to be powered down immediately. Two thirds of units reported a safety system failure to the NRC in 2009 as well.

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<sup>87</sup> Pinkerton LE, Bloom TF, Hein MJ, Ward EM. 2004. Mortality among a cohort of uranium mill workers: an update. *Occup Environ Med.* 61:57-64

<sup>88</sup> EPA, 2010. Uravan Uranium.

<http://web.archive.org/web/20040908170056/http://www.epa.gov/region08/sf/sites/co/uravan.html>

<sup>89</sup> Records and documents at the West Valley site, in upstate New York, indicate that "waste containers consisting of 55-gallon drums and rectangular containers made of cardboard, wood, and concrete were laid into the trench by hand and stacked on their sides" in a river valley where the "valley walls ... are steep and badly slumped." EPA, 1977. Summary Report on the Low-Level Radioactive Waste Burial Site, West Valley, New York (1963-1975).

<sup>90</sup> Of 51 high level and mixed waste tanks at the Savannah River Site, 12 have a history of leakage. US NRC, 2010. Savannah River Site Disposal Facility for Waste Incidental to Reprocessing.

<http://www.nrc.gov/waste/incidental-waste/wir-process/wir-locations/wir-srs.html>

<sup>91</sup> Synapse Energy Economics. 2008. The Real Costs of Cleaning up Nuclear Waste: A Full Cost Accounting of Cleanup Options for the West Valley Nuclear Waste Site.

<http://www.nirs.org/radwaste/decommissioning/wvfcareport1108.pdf>

<sup>92</sup> Pacific Northwest National Laboratory. 1998. Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Area S-SX at the Hanford Site.

<http://www.hanford.gov/docs/pnnl-11810/11810.pdf>

<sup>93</sup> US GAO, 2009. Nuclear Waste: Uncertainties and Questions about Costs and Risks Persist with DOE's Tank Waste Cleanup Strategy at Hanford.

<sup>94</sup> World Health Organization. Health Effects of the Chernobyl Accident: An Overview.

<http://www.who.int/mediacentre/factsheets/fs303/en/index.html>

<sup>95</sup> NRC. 2010. Fiscal Year 2009 Results of the Industry Trends Program for Operating Power Reactors.

<http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2010/secy2010-0028/2010-0028scypdf>

- In January of 2010, a tritium leak at the Vermont Yankee nuclear power station posed enough social discomfort that the Vermont state legislature voted to not allow the station to continue operations past 2012.<sup>96</sup>

The US public partially pays for nuclear externalities through three mechanisms:

1. A small surcharge of 1 mill (one one-hundredth of a cent) per kWh is collected to pay for collective waste disposal needs. However, this fund is not designed to be used as insurance against remediating radioactive contamination, much less insure against accidents for the full aging fleet;
2. Incremental cleanup efforts at contaminated federal nuclear waste repositories and processing centers, paid for by US taxpayers through the US DOE; and
3. Risk premiums imposed by lenders on the nuclear industry for building and operating new nuclear facilities. This informal premium exacts a very real opportunity cost for building new nuclear facilities; however, the federal government now offers low interest loans to the nuclear industry, ensured by US taxpayers, to build new nuclear plants and overcome this risk premium.<sup>97</sup>

Many of the externalities associated with nuclear power remain uncaptured. This is in part because some of these impacts are difficult to quantify. The risks from radioactive waste are debated and, depending on the level of contamination, the pathway into the environment, and the type of waste involved, highly variable. Risk mitigation has improved over time, but as the most recent financial crisis has shown, risks can only be hedged to the extent that they are accurately anticipated in the first place.

### ***Nuclear Waste***

Currently, nuclear waste is stored at the generation sites or in state. Most of these storage sites, however, were developed under the explicit assumption that they would be temporary, which means they are both too small and too weak to prevent the spread of radioactive material in the event of a severe accident. Centralized storage facilities are expensive (estimates for the Yucca mountain project in Nevada have put development costs at nearly \$100 billion)<sup>98</sup> and require the transportation of large quantities of nuclear waste across the country, introducing a host of security and safety issues.

Radioactive waste is generally divided into three categories: low-level waste, high level waste, and transuranic waste.

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<sup>96</sup> Matthew L. Wald. Vermont Senate Votes to Close Nuclear Plant The New York Times, February 24, 2010.

<sup>97</sup> US DOE. 2010. President Obama Announces Loan Guarantees to Construct New Nuclear Power Reactors in Georgia. <http://www.energy.gov/news/8643.htm>

<sup>98</sup> "Yucca mountain estimate cost estimate rises to \$96 billion", World Nuclear News, August 6, 2008, <http://www.world-nuclear-news.org/newsarticle.aspx?id=20196>

- **High-level waste** consists of spent nuclear fuel and related fission products as well as any reprocessed waste products (the United States does not currently reprocess spent fuel, so high-level waste in this context will only refer to spent nuclear fuel).
- **Transuranic waste** is any waste product of the fission process that is above uranium on the periodic table, such as plutonium. Transuranic elements do not appear naturally on Earth, and so only occur as the byproduct of the nuclear fission process.
- **Low-level waste** is the broadest category as it is essentially defined by what it is not – the category covers any radioactive waste product that is not high-level or transuranic. Any material used in the handling or storage of radioactive materials is considered low-level waste, which means everything from the gloves and suits worn by workers at nuclear facilities who come in contact with radioactive material to the highly radioactive metals and concrete used in the reactor core.

Low-level waste makes up 90% of the volume of radioactive waste products, but only 1% of the radioactivity. Most radioactive waste is maintained at nuclear facilities, but some is transported to disposal sites. For example, in 2008, utilities shipped 5,300 cubic meters of low-level radioactive waste,<sup>99, 100</sup> but maintained most waste on-site.

From a health and safety perspective, high-level and transuranic waste are both the most severe and long-term hazards. The largest byproduct of the fission process is uranium, a high-level waste product with an extremely long half-life (U-238, which is not fissile material, has a half-life of 4.47 billion years, and U-235, which is fissile, has a half-life of 700 million years). Uranium decay produces alpha particles, which can damage cells but cannot penetrate human skin; uranium is only considered acutely harmful if it is inhaled or swallowed. Once in the body uranium tends to concentrate in the kidneys and skeleton, leading to kidney damage or cancer.<sup>101</sup>

Plutonium, a transuranic element with a half-life of 24,130 years, makes up about 1% of nuclear waste. As with uranium, plutonium decay releases alpha particles, and so it is only harmful if inhaled (plutonium does not easily pass through the lining of the stomach or intestines, and so is less harmful if swallowed).<sup>102</sup> The relatively shorter half-life of plutonium, however, is a result of it being more radioactive, so the consequences if inhaled are far more severe. Plutonium concentrates in the liver, skeleton, kidneys and gonads, and can stay in the body for decades. It is very cancerous even in extremely minute quantities.

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<sup>99</sup> Department of Energy, Manifest Information Management System (MIMS), <http://mims.apps.em.doe.gov/>

<sup>100</sup> Significant amounts of shipped waste are compressed before being stored as storage facilities charge by volume, and so producers have a strong incentive to keep that volume as low as possible, and some plants have permission to burn their low-level waste, instead of sending it out to be stored.

<sup>101</sup> "Radioactive waste: what health effects, or risks?", Clefs CEA No. 53, Winter 2005-2006

<sup>102</sup> U.S. Environmental Protection Agency

While there are number of other radioactive waste products associated with the nuclear fuel cycle, the majority of the radioactivity in nuclear waste comes from two fission products: strontium-90 and cesium-137. Each has a half-life of about 30 years. Strontium-90 is used in medical studies as a radioactive tracer, and so does have some commercial value. It is, however, quite dangerous, especially in larger quantities, mainly because it has similar properties to calcium. When ingested, strontium-90 tends to bind with bone, where it can cause bone cancer and leukemia. Cesium-137 decay releases beta particles (high-energy electrons) and gamma rays (high-frequency electromagnetic radiation), both of which can penetrate the skin. Cesium-137 is therefore dangerous to be near even if it is not ingested or inhaled. Exposure to large quantities can lead to cancer as well as serious burns or even death.

From a long-term perspective, the most troubling nuclear waste products are Technetium-99, which is both extremely radioactive and, with a half-life of 220,000 years, very long-lived, and Iodine-129, which is not highly radioactive (it has a half-life of 17 million years) but is an extremely noxious carcinogen. Both Technetium-99 and Iodine-129 tend to concentrate in the thyroid gland.

Actual levels of high-level and transuranic waste produced vary depending on the size and efficiency of the nuclear reactor. Pressurized water reactors (PWR) tend to produce less waste, for example, than boiling water reactors (BWR). A typical 1,000 MW nuclear plant might produce around 30 tons of high-level waste a year. The US currently has 104 nuclear reactors (69 PWR and 35 BWR) with a total capacity of around 101,000 MW,<sup>103</sup> so annual production of high-level waste is around 3,000 tons. Currently the majority this waste is stored on site – that is, at the location where it is produced – while the rest is stored in nearby temporary storage sites. Out of 104 active nuclear power plants, 68 have run out of local storage space or will run out this year. Of the rest, all are expected to run out of space by 2026.<sup>104</sup>

The federal government has mandated that all high-level waste be moved to some centralized storage site, but development of the Yucca mountain site in Nevada, which was intended to be the first of three such sites, has been postponed indefinitely due to safety and security concerns.

Long-term storage raises questions about the safety of transportation and long-term storage facility integrity.

- **Transportation** becomes problematic because US nuclear facilities are spread out across the country, so maintaining a unified storage site requires the transport of high-level waste over long distances (see **Figure 23**, below) which in turn exposes nuclear waste to the possibility of accidents, attack, or theft.

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<sup>103</sup> “Nuclear Power in the USA”, World Nuclear Association, <http://www.world-nuclear.org/info/inf41.html>

<sup>104</sup> “Status of Used Nuclear Fuel Storage at U.S. Commercial Nuclear Plants”, July 2010, Nuclear Energy Institute, <http://www.nei.org/resourcesandstats/documentlibrary/nuclearwastedisposal/factsheet/statusofusednuclearfuelstorage/>



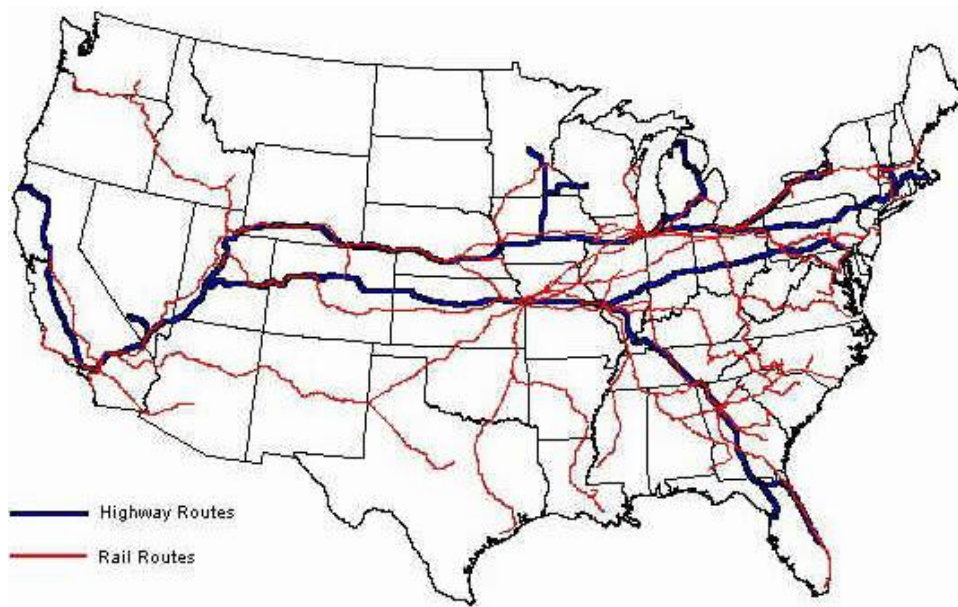


Figure 23. Nuclear waste shipment routes to Yucca Mountain: potential highway and rail routes from existing nuclear generators.<sup>105</sup>

- **Storage system integrity** becomes a problem over periods of decades to centuries to millennia. Radioactive material remains dangerous hundreds to hundreds of thousands of years (some isotopes remain toxic for millions of years). The intended facility at Yucca Mountain is designed to secure waste for 10,000 years,<sup>106</sup> but geologists are uncertain about the geological stability and groundwater penetration over that period. There are no analogs of a site remaining fully integral during such a long span (there is scant archeological evidence from 10,000 years ago, around the period of the last glacial maximum).

To illustrate the amount of waste which is under consideration, we estimate the amount of nuclear waste generated in the Reference Case and the Transition Scenarios. These values are estimated in Section 8.2, below.

### ***Nuclear Accidents***

The cost to society of a nuclear accident can theoretically be quantified by multiplying the social cost of an accident (measured in terms of lives lost, increased rates of cancer and other diseases, and the value of irradiated land). Quantifying the risk of a severe accident is open to significant interpretation. There has only be one significant nuclear meltdown (Chernobyl, in Ukraine), which leads some to argue that the risk of an accident is relatively low. Others point to the near meltdown of Three Mile Island and the recent radioactive leak at Vermont Yankee as evidence that even countries with strong regulatory oversight of their nuclear facilities are not immune from potential disaster.

<sup>105</sup> State of Nevada. 2009. Nuclear Waste Transportation Routes.

<http://www.state.nv.us/nucwaste/states/us.htm>

<sup>106</sup> "About Yucca Mountain Standards", Environmental Protection Agency, <http://www.epa.gov/rpdweb00/yucca/about.html>

The case of Vermont Yankee shows quite directly how even relatively small accidents can have a dramatic impact on public support for nuclear power. In January 2010, Entergy (Vermont Yankee's owner) revealed that a small amount of radioactive tritium was found in a test well. While tritium is not particularly harmful, the mere fact that it had escaped unnoticed did significant damage to public support for the plant. As a result, Vermont denied the extension of the nuclear plant's license. At 38 years old, Vermont Yankee is a relatively young plant. It is not unreasonable to ask what issues may have gone unnoticed at other, older plants.

### ***Upstream Costs: Mining, Milling, and Processing***

Like all mining activity, mining for uranium can wreak a heavy toll on the environment and produces significant quantities of waste. Water use in a typical uranium mine is approximately 200 to 300 gallons per minute,<sup>107</sup> and a mine requires more than 220 acres of land to be set aside permanently for waste rock and radioactive tailing storage.<sup>108</sup> Over time the radioactivity of the tailing material can grow to be about 75% of that of the original ore.<sup>109</sup>

The US does not consider radioactive tailings to be strictly-defined radioactive waste, and so it is treated as regular tailing material, first covered in water and then in a layer of clay and rock to prevent the leakage of radon gas and other dangerous materials. The fact that tailing material is not considered radioactive waste means the true cost of this waste product may not be fully appreciated. It is entirely possible that at some point down the road this material will be deemed radioactive and so would therefore require either reinforced storage at the site itself or transportation to some centralized storage facility.

The main physical danger that separates uranium mining from other ore mining is the close exposure to radioactive material. Some studies have found increased rates of cancer or damaged DNA in mine workers, though there have been few global studies on the subject.<sup>110</sup> Most of the uranium mining in the US, as well as in Australia and Kazakhstan (which together have about 43% of the world's known supply of uranium) is done via in situ leaching. This involves dissolving the uranium ore into a solution in place and then pumping it to the surface, where it is collected in ground pools. This lowers the direct risk to miners, though it is not without its own environmental costs (including increase water use and chemical saturation of the ground). It is also worth pointing out that the US has only 4% of the world's recoverable uranium supply, and the majority of that is relatively expensive to mine. The continued use of nuclear power means relying on foreign sources for fuel. In evaluating the social cost of mining uranium, it is important to bear in mind the conditions of the mines internationally, and the environmental cost of transporting uranium from literally the other side of the globe.

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<sup>107</sup> "Estimating Externalities of Nuclear Fuel Cycles", Oak Ridge National Laboratory and Resources for the Future, section 5.7.2

<sup>108</sup> "Estimating Externalities of Nuclear Fuel Cycles", section 5.7.3

<sup>109</sup> Radioactive Waste Management: Mining and Milling", World Nuclear Association, <http://www.world-nuclear.org/info/inf04.html>

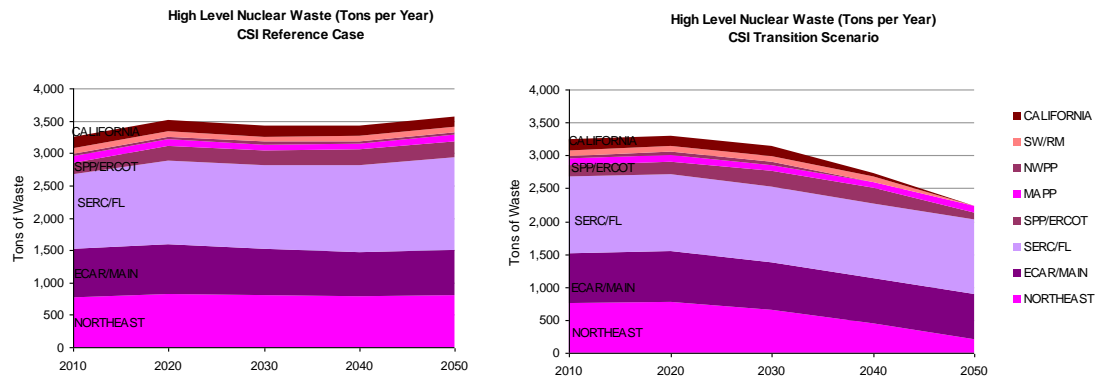
<sup>110</sup> World Information Service on Energy, Uranium Project

## 8.2. Avoided nuclear waste in Transition Scenario

To estimate the amount of nuclear waste generated under both our reference case and the transition scenario we first determined the amount of nuclear waste that had been generated historically. The EIA has published total waste figures by plant type (PWR and BWR) from 1968 to 2002.<sup>111</sup> This data also includes the amount of energy that was released during the fission process, but only in terms of thermal gigawatt-days. To determine the amount of waste produced in terms of electric gigawatt-hours we must first convert thermal to electric using some conversion factor. We chose a conversion factor of 33%, which the EIA has indicated is appropriate for the type of reactors used in the US.<sup>112</sup> Based on the average amount of waste produced over the twenty year period from 1983 to 2002, we determined that a typical PWR reactor produces 3.4 metric tons of nuclear waste for every TWh of electricity produced, while the less efficient BWR reactors produce 4.1 metric tons of nuclear waste for every TWh of electricity.

Based on the assumed nuclear generation from our reference case and transition scenario, it was then possible to determine the amount of nuclear waste that would be avoided as the amount of nuclear generation was reduced. In doing so, we assumed that all nuclear generation built in the Reference Case would echo the existing fleet's composition between BWR and PWR reactors, and that the Transition Scenario would simply retire a *pro-rata* share of the existing fleet.

The net result of this analysis is that in the Reference Case, while nuclear power grows moderately from 2010 to 2050, total waste grows by 20% in the Reference Case (see **Figure 24**). The Transition Scenario avoids about 36% of the waste of the Reference case (see **Figure 25**).



**Figure 24. Creation of high-level nuclear waste in the Reference Case and Transition scenarios, respectively.**

The Transition Scenario avoids significant nuclear waste towards the later part of the analysis period. Between 2020 and 2030, the energy analysis maintains much of the

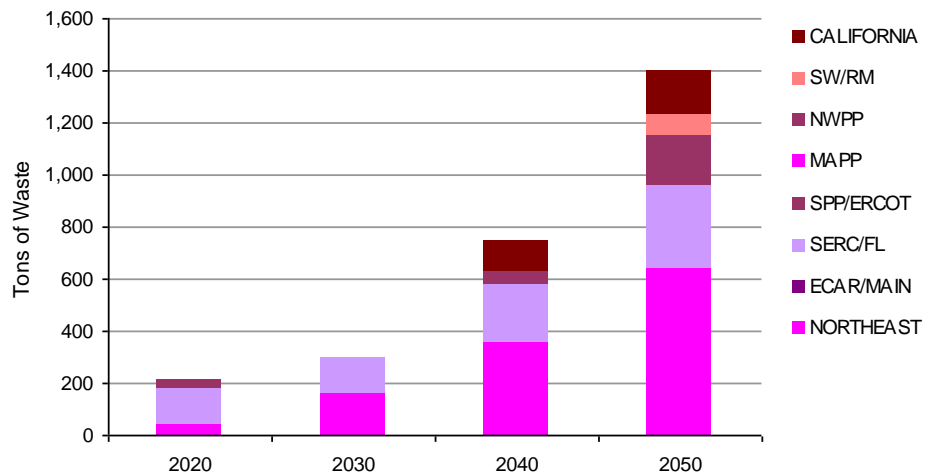
<sup>111</sup> EIA, U.S. Radioactive Waste and Spent Nuclear Fuel, Detailed U.S. Spent Nuclear Fuel Data –

Table 3

<sup>112</sup> [http://www.eia.doe.gov/cneaf/nuclear/page/uran\\_enrich\\_fuel/convert.html](http://www.eia.doe.gov/cneaf/nuclear/page/uran_enrich_fuel/convert.html)

existing (or repowered components) nuclear fleet to support the retirement of the existing coal fleet. As new renewable energy infrastructure is brought online and energy efficiency measures are brought into full force, reducing demand, increasing numbers of generators are able to be taken offline, increasing the avoided high level waste produced in the Transition Scenario (see **Figure 25**). In the analysis, California, the Northeast (New York and New England) and the Northwest are all able to find alternatives to replacing nuclear units by 2050, and therefore avoid significant waste in the out years.

**Avoided High Level Nuclear Waste (Tons per Year)**



**Figure 25. Avoided high-level nuclear waste in the Transition Scenario**

## 9. Conclusions

The US electric sector imposes a significant yet undervalued burden on society. Toxic emissions, climate-change inducing carbon dioxide emissions, the use and consumption of large amounts of water, and the generation of large quantities of poisonous waste are essentially unpriced in the energy market.

This report begins to quantify some of the externalities of the current coal fleet and the benefits of retiring the fleet over the next decades. The externalities identified here are real, significant, and large. Ignoring carbon and toxic emissions, taxing water withdrawals and consumption, and waste disposal shifts social burdens from the utilities to society, imparting increased healthcare costs, lost lives, damaged fisheries and ecosystems, and the numerous problems associated with global climate change.

There are currently few routes through which the costs of these externalities are realized or even shown to the market. One route by which externalities are re-internalized back into the energy sector is through legislation and rules designed to protect the public from harm. Historic actions, or lack thereof, by electric producers has indicated that external costs are either not considered or deeply undervalued by those who choose to pollute. It can be argued that the only mechanism for capturing external costs is through effective regulation and rulemaking in the public good.

Today, the EPA is looking to implement a series of tough environmental reforms in the electricity sector, including regulations governing emissions, water use, and coal ash. These regulations, implemented individually, would address some of the externalities described here, but would fail to capture all of the external costs. It is likely that the cost to consumers to adequately address all of the social costs of generating electricity from the existing coal fleet is significantly higher than the marginal cost of simply replacing the existing fleet with clean resources, such as renewable energy and efficient energy use.

The costs of generation are not simply the tangible costs to consumers, but also the costs imparted upon society. By reducing these costs, the Transition Scenario has significant benefits to society.