2-26-09 Alternative Energy in Arctic and Subarctic Alaska

<target><bill></bill><subject>2-26-09   Alternative Energy in Arctic and Subarctic Alaska</subject><comm>SWTR26</comm></target>

1298

New Energy: The U.S. Arctic Research Program and Alaska

Mead Treadwell, Chair
U.S. Arctic Research Commission

Slides accompanying testimony to the
Alaska Senate Special Committee on World Trade, Technology, Innovation
Juneau, Alaska – February 26, 2009

US ARCTIC RESEARCH COMMISSION

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Helvi Sandvik

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Vera Kingeekuk Metcalf

Warren Zapol

Charles Vörösmarty

1301

Arctic Research in the US

- The U.S. Arctic Research Program is approximately $400 million per year…across at least 15 federal agencies…cooperating with over a dozen nations …using research infrastructure worth billions…and building America's competitive position

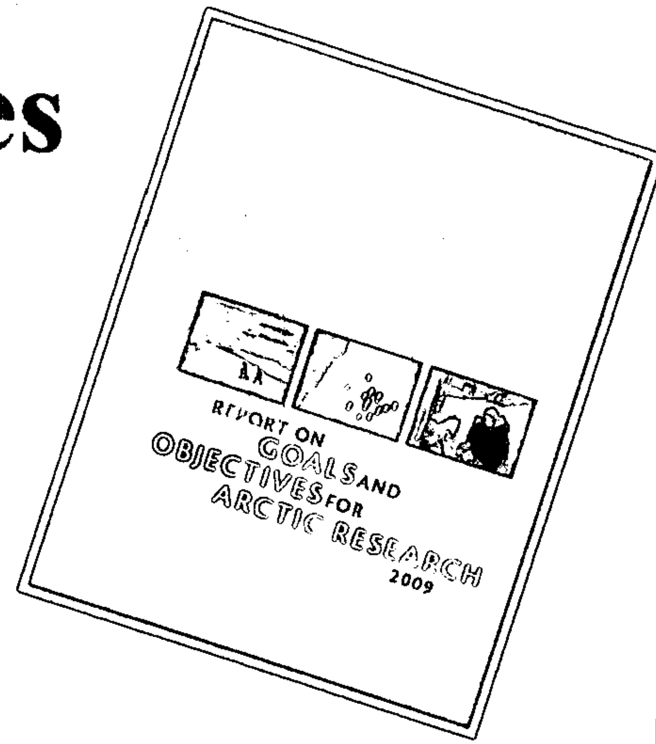
UNITED STATES ARCTIC RESEARCH COMMISSION

1302

REPORT ON GOALS AND OBJECTIVES FOR ARCTIC RESEARCH 2009

1303

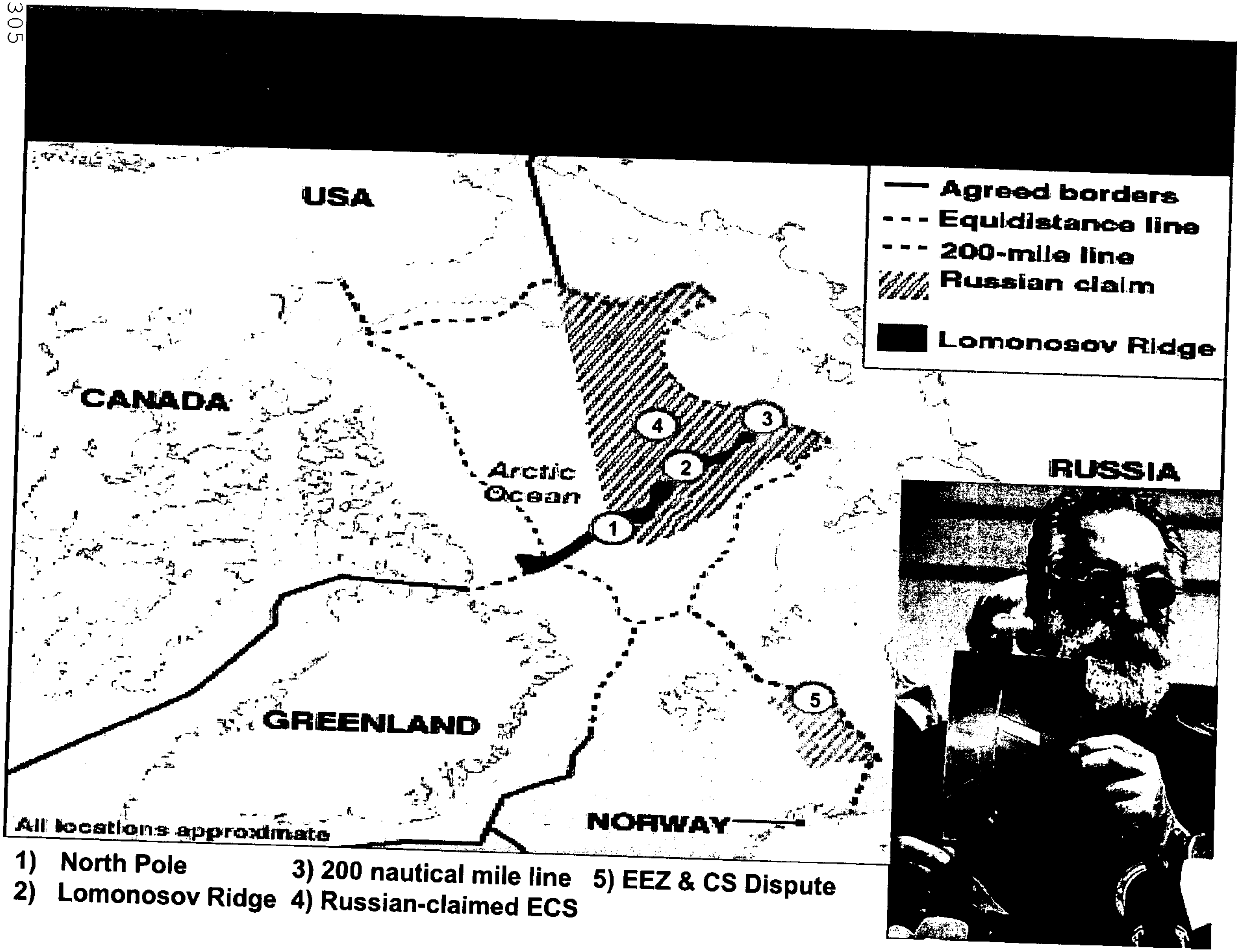
Research Themes



- Environmental Change of the Arctic & Bering Seas
- Arctic Human Health
- Civil Infrastructure
- Natural Resource Assessment & Earth Science
- Indigenous Languages, Identities, Cultures

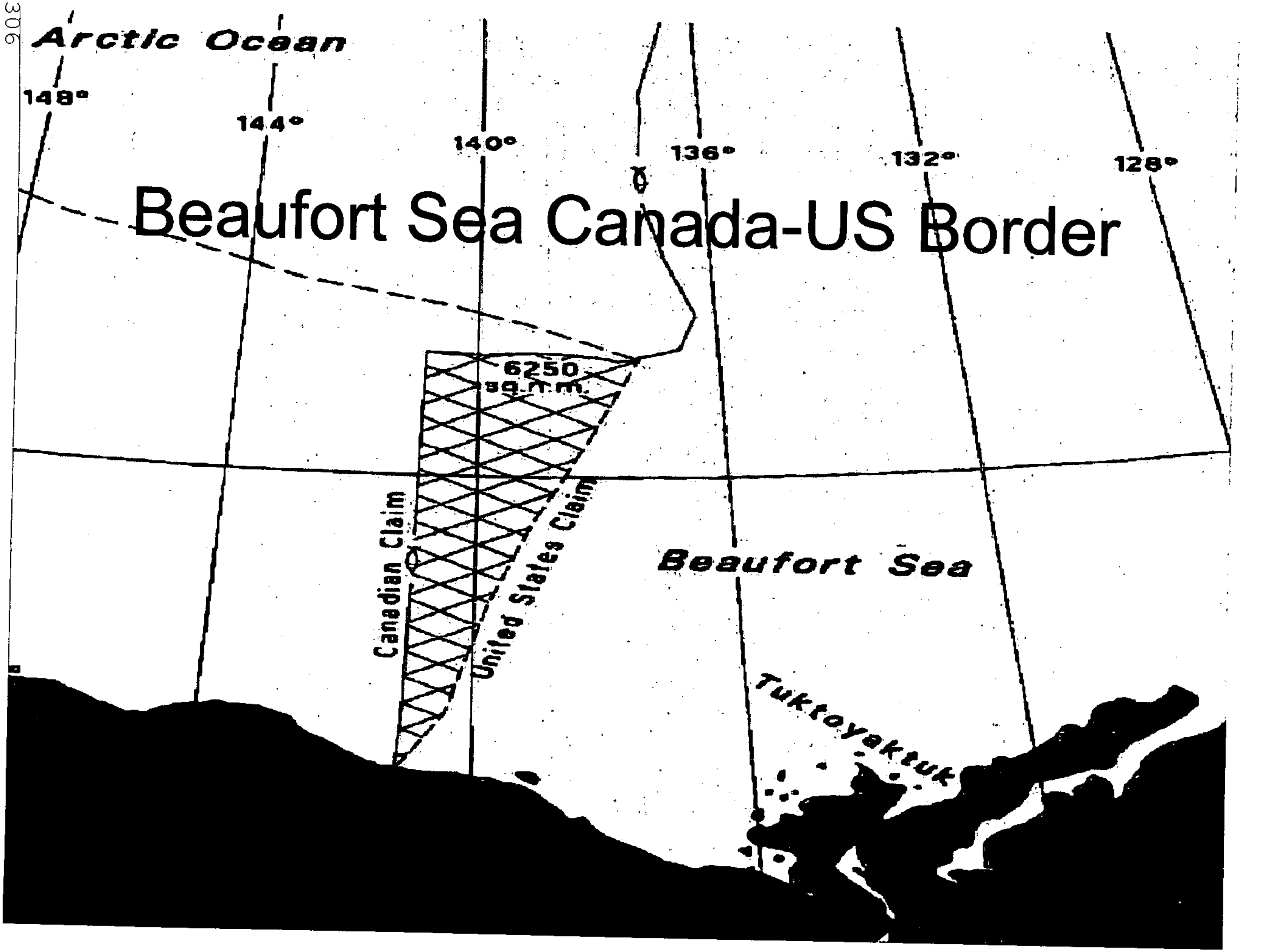
New US Arctic Policy

- National security/homeland security needs
- Protect environment/conserve biological resources
- Environmentally sustainable resource management and development
- Strengthen institutions for international cooperation; ratify Law of the Sea
- Involve indigenous communities in decisions
- Enhance scientific monitoring and research into local, regional and global environmental issues



1) North Pole
2) Lomonosov Ridge
3) 200 nautical mile line
4) Russian-claimed ECS
5) EEZ & CS Dispute

Beaufort Sea Canada-US Border



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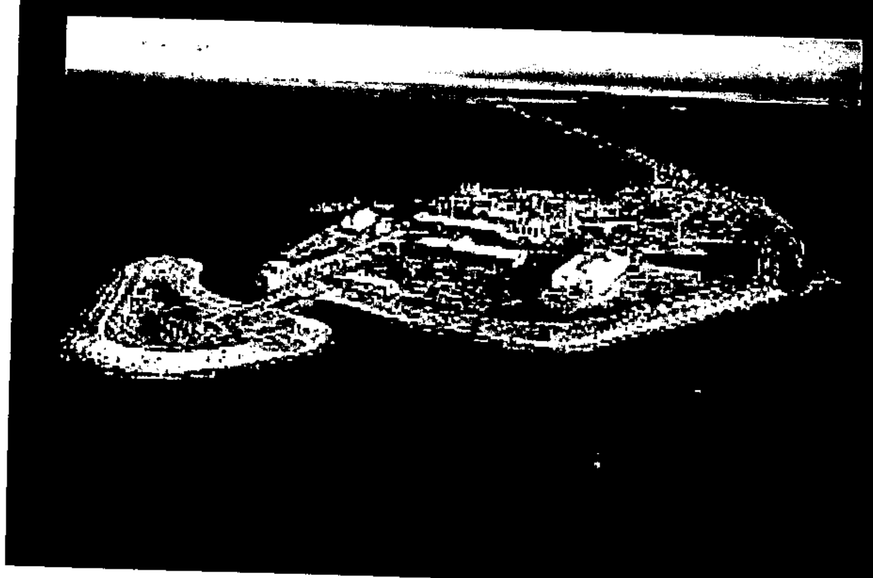
UNITED STATES ARCTIC RESEARCH COMMISSION

INSTITUTE OF THE NORTH

THE ARCTIC ENERGY SUMMIT



AN INTERNATIONAL POLAR YEAR EVENT

ARCTIC ENERGY
Themes

RURAL

EXTRACTIVE

SUSTAINABILITY

New Energy

- Arctic energy research in Alaska has global implications
  - Safer, more efficient fossil fuel development
    - New exploration techniques, onshore and offshore
    - Longer winter drilling seasons in a warming climate
    - Improvements in cold weather spill prevention, response
    - Safe, secure, reliable shipping
    - Carbon sequestration, use of gas hydrates

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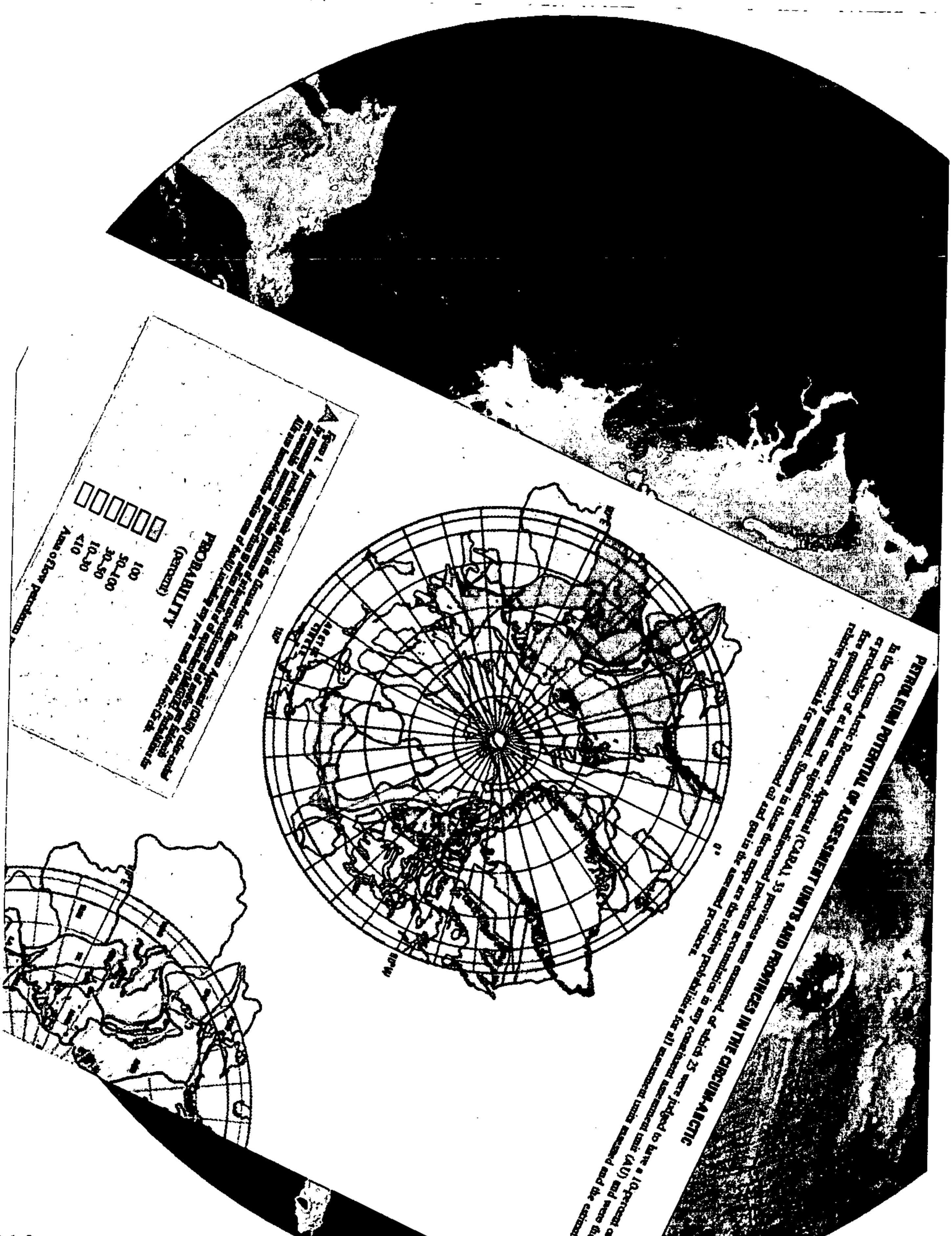
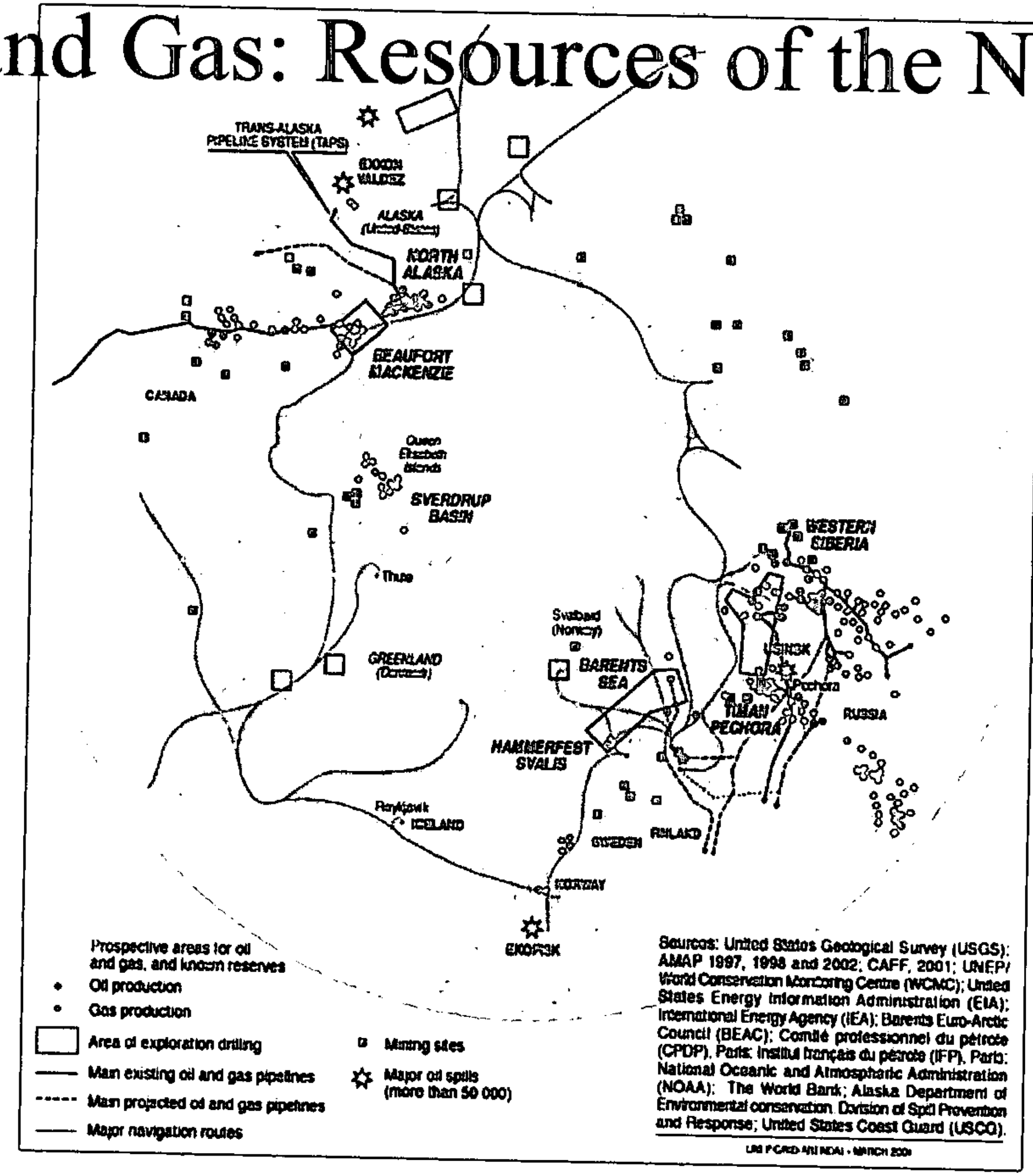
New Energy

- Our motivation can be stabilizing costs AND mitigating global climate change
  - Our focus can be rural AND urban AND export
  - Onshore and offshore
  - Electric power, heat, and all transport modes
  - Alaska's natural assets include hydro, wind, tides, geothermal, waves, biomass, solar…
  - Arctic may be a "geoengineering" venue as well
  - Alaska may play in new transport routes as well



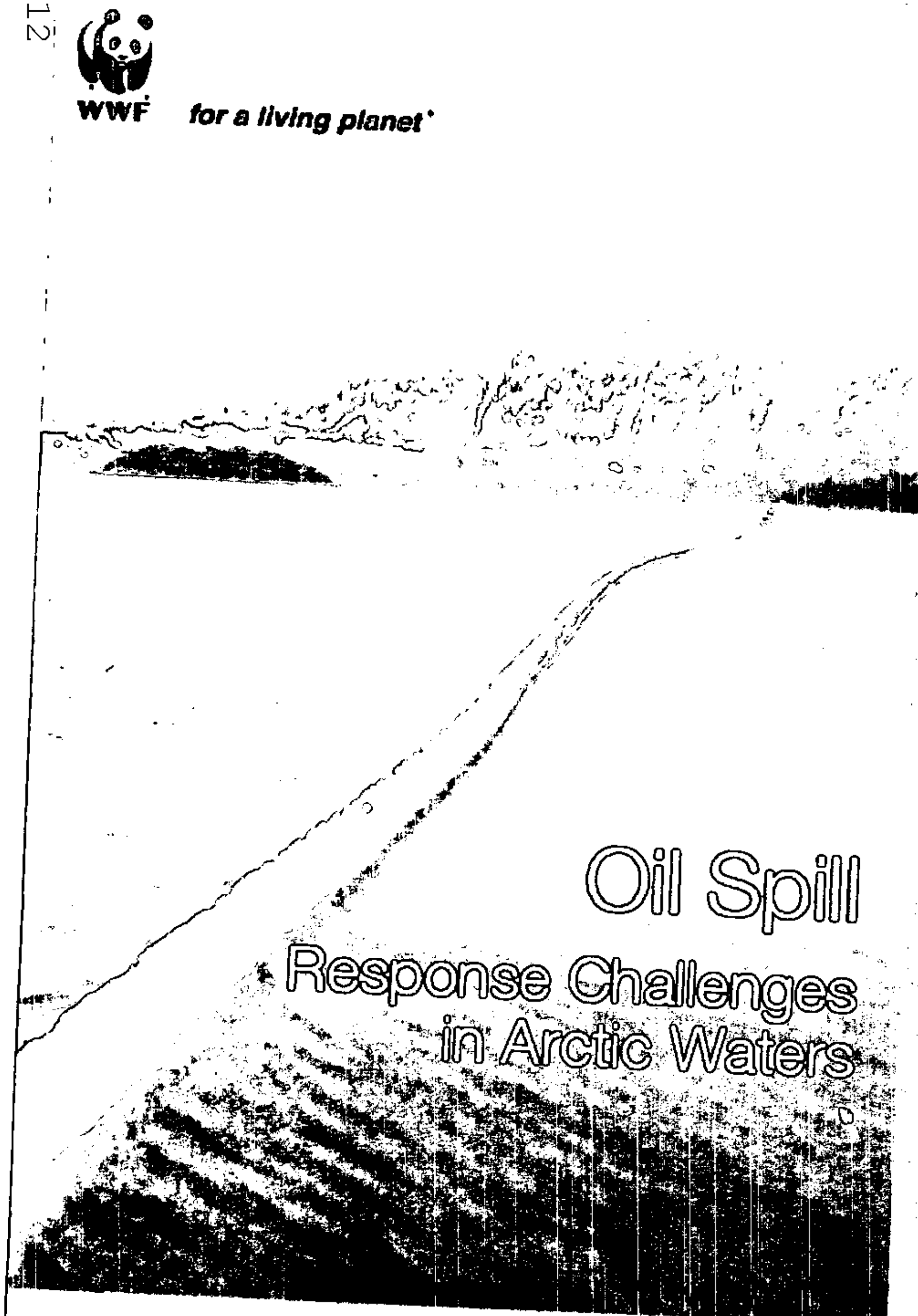
PETROLEUM POTENTIAL OF ASSESSMENT UNITS AND PROVINCES IN THE CIRCUM-ARCTIC
PROBABILITY
(percent)
100
50–100
30–50
10–30
<10

Oil and Gas: Resources of the North



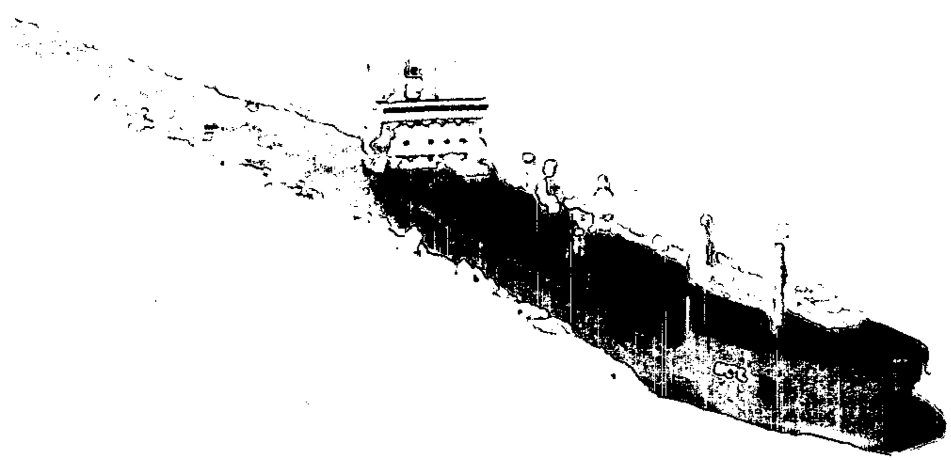
Source: AMAP

1312



- Federally supported oil in ice research continues, in international programs, supported by several agencies

1313



"Demand for ice-class tankers has been steadily rising as oil exports from Russia's Arctic regions become ever more attractive. The ordering pace...in the tanker industry... (reached) some $4.5 billion in (2004) alone."

--American Bureau of Shipping, *Surveyor*, Summer 2005

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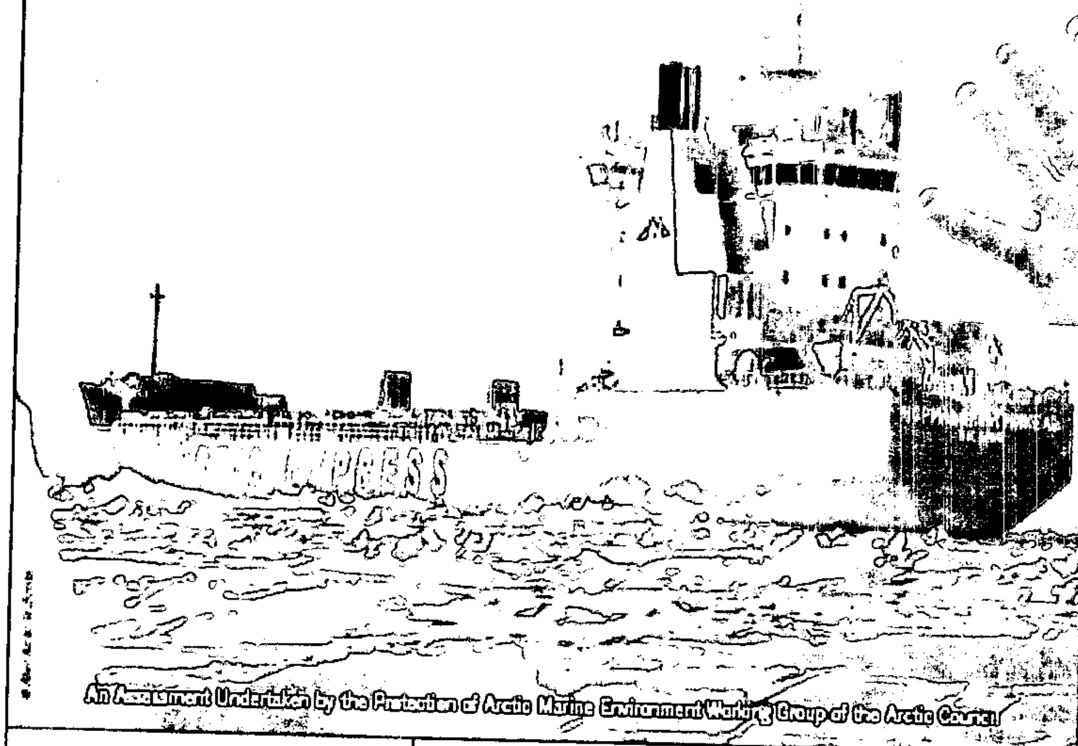
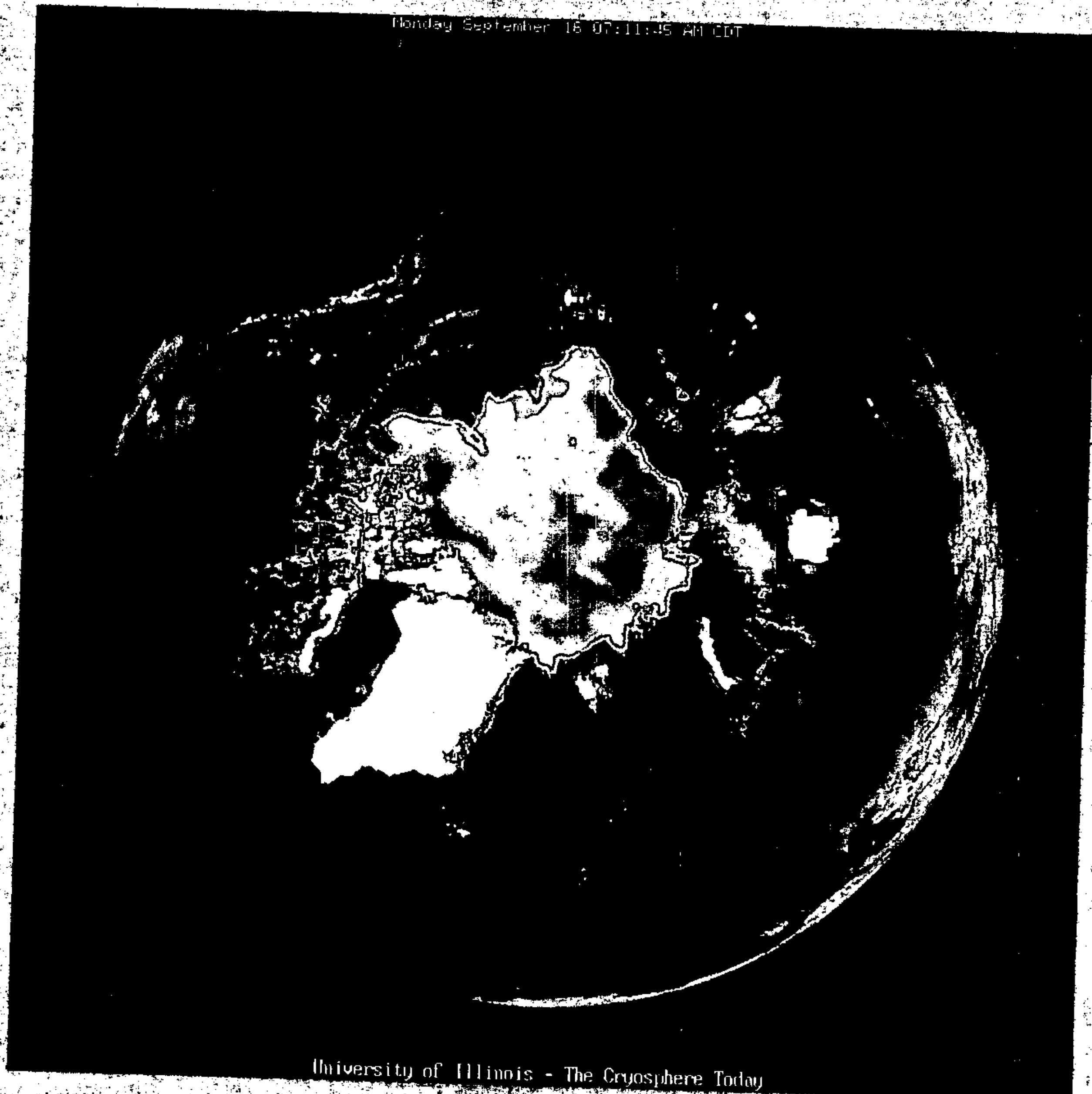
ARCTIC MARINE SHIPPING ASSESSMENT



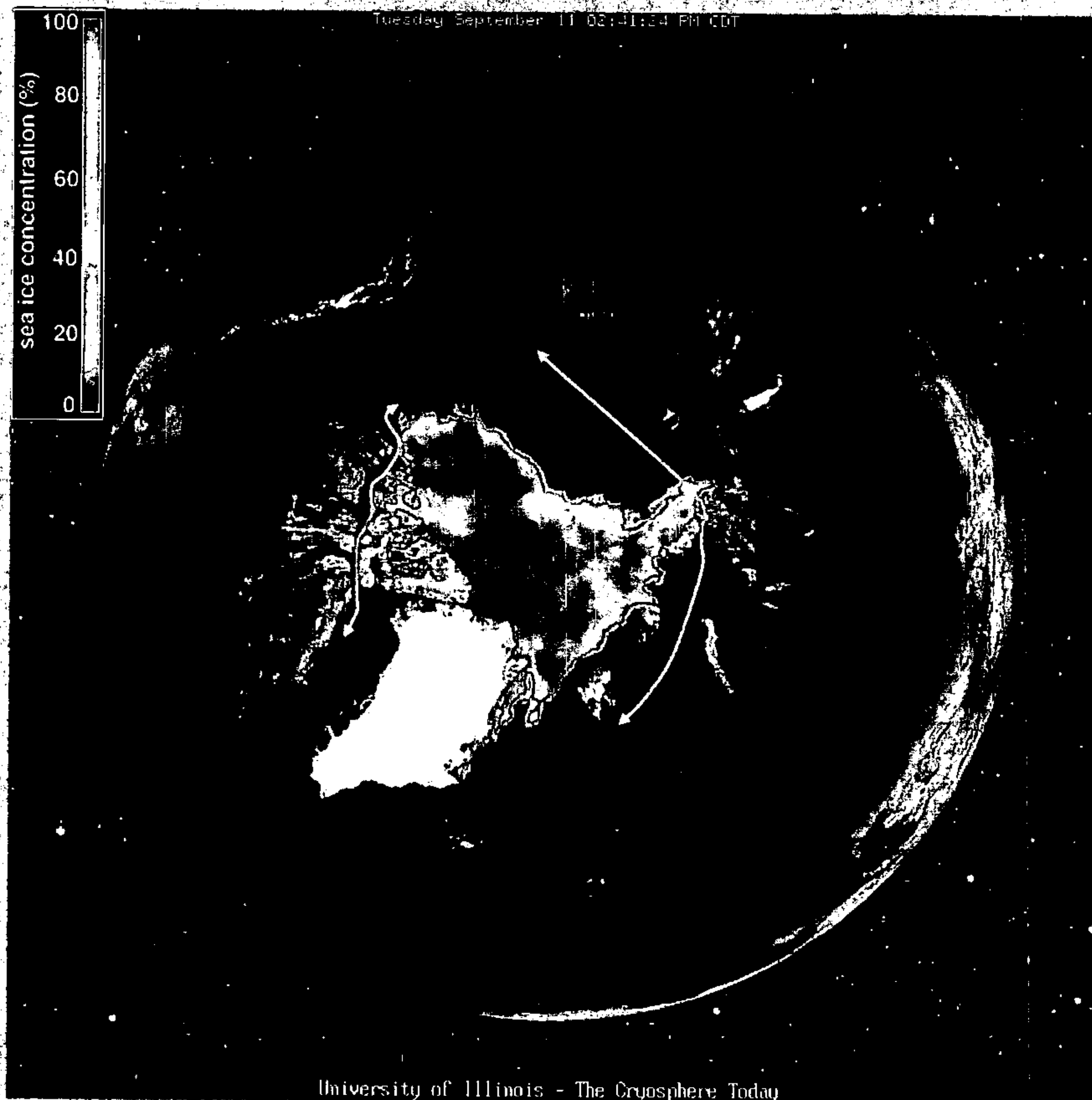
An Assessment Undertaken by the Protection of Arctic Marine Environment Working Group of the Arctic Council

PAME

16 September 2002



11 September 2007



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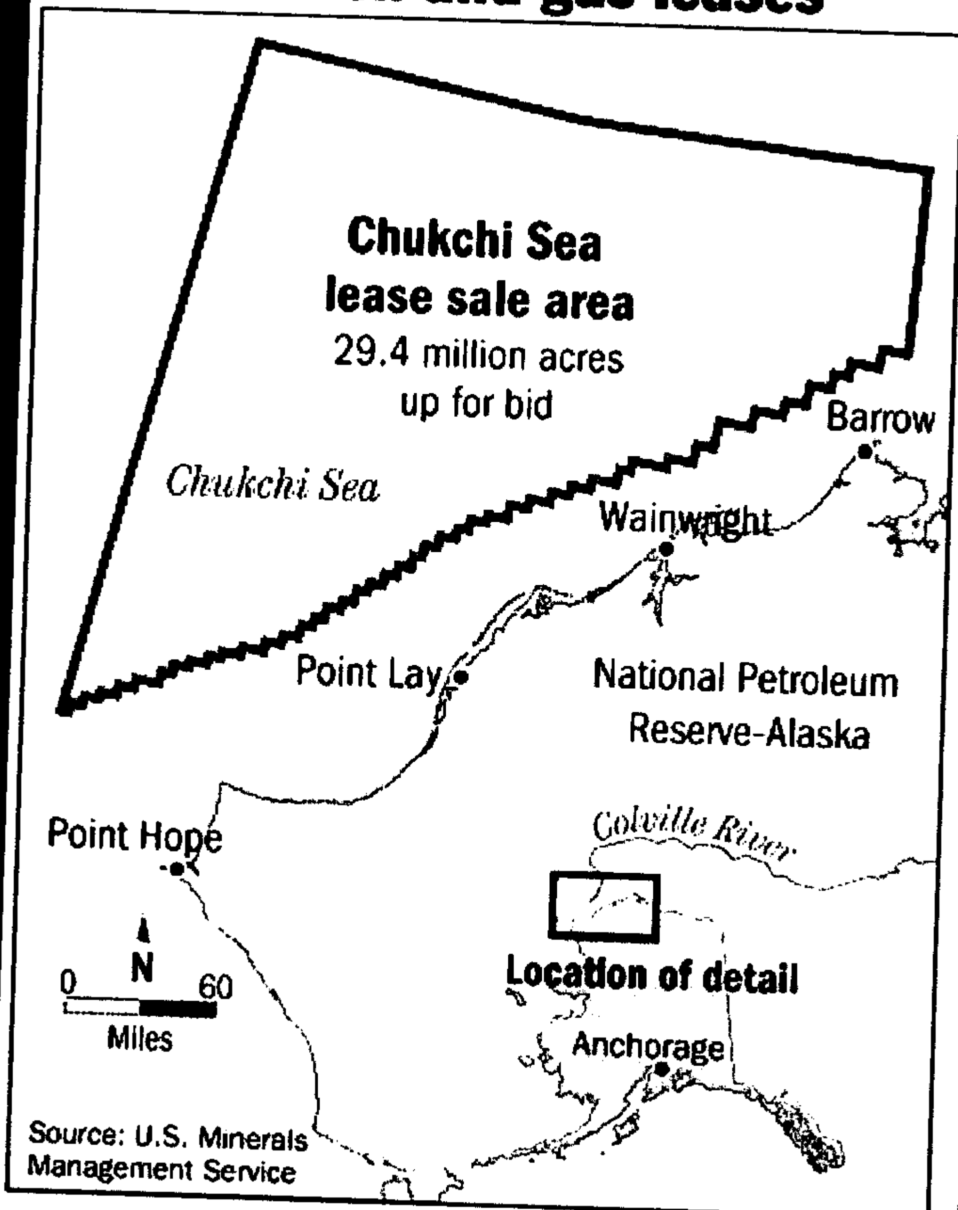
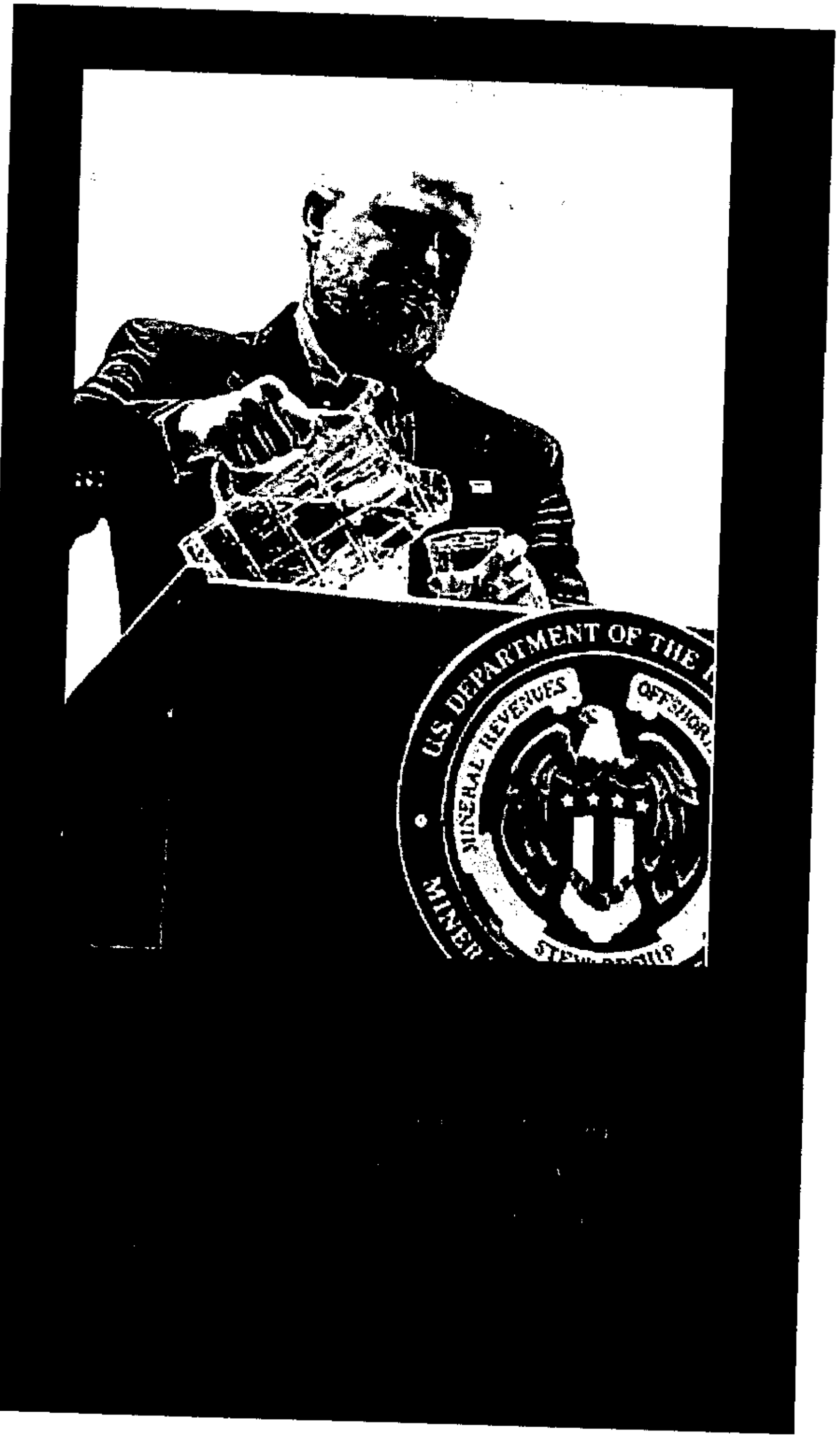
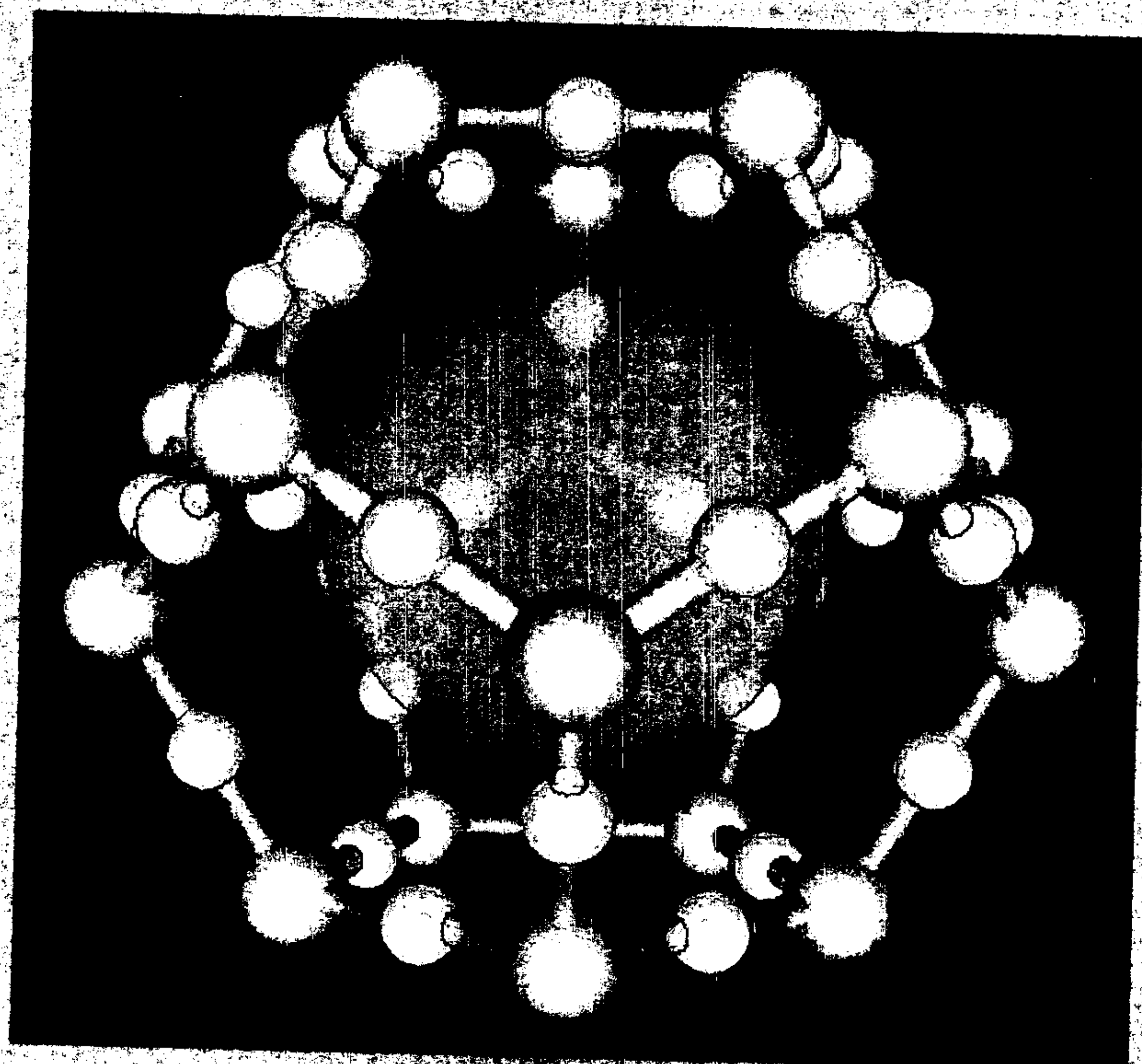
Record $2.7 billion bid for Alaska oil and gas leases

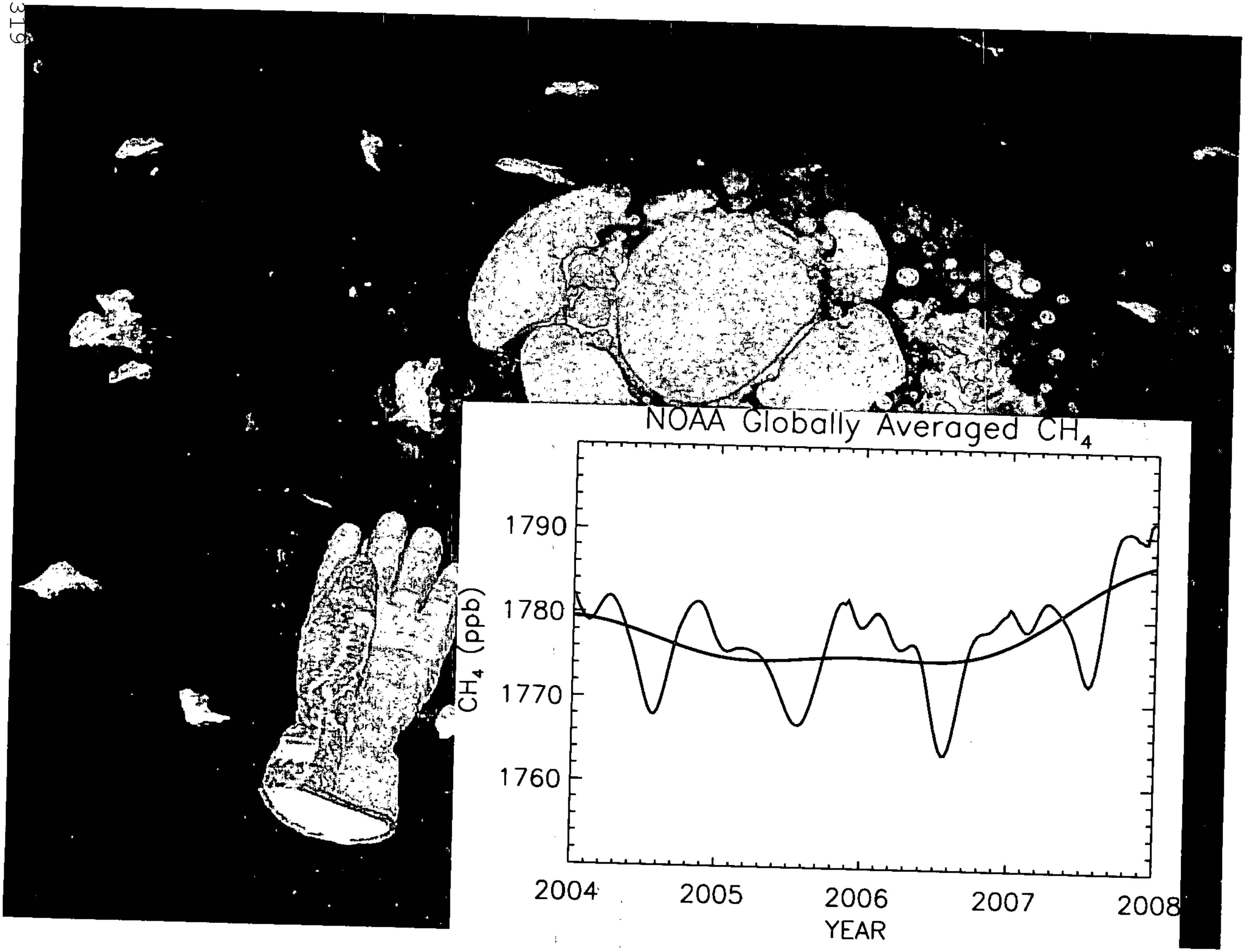


RON ENGSTROM / Anchorage Daily News



Gas Hydrate Research




NOAA Globally Averaged CH_4
CH_4 (ppb)
1790
1780
1770
1760
2004
2005
2006
2007
2008
YEAR

DOE/PI-0005

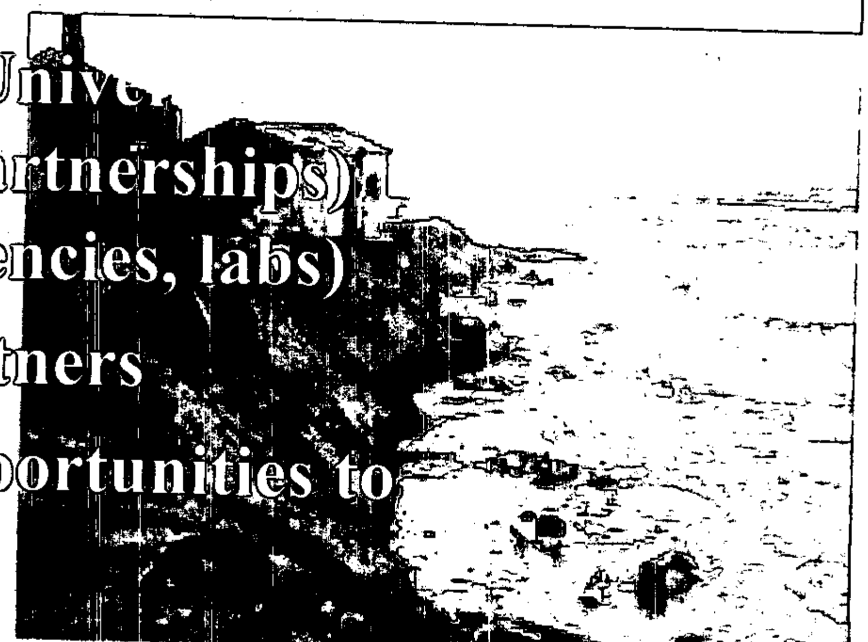
U.S. Climate Change Technology Program

STRATEGIC PLAN

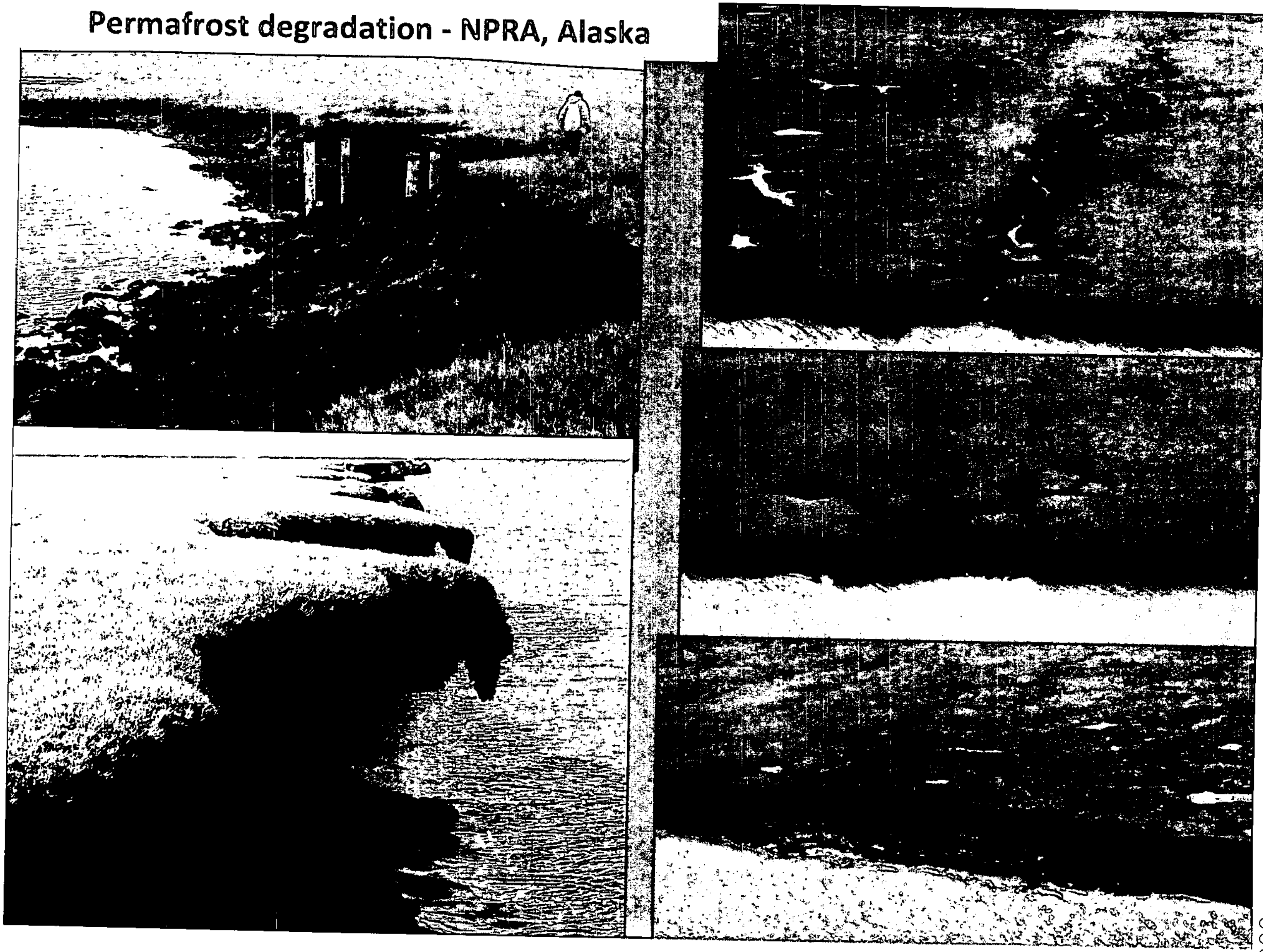
September 2006

1321

- How do we develop a research plan?
  - Convene experts
  - Find clients (resource managers, builders, lenders, insurers)
  - Extramural (Competitive Unive research; Public-Private Partnerships) vs. Intramural (Federal agencies, labs)
  - International and state partners
  - Pilot projects and other opportunities to test



Permafrost degradation - NPRA, Alaska



Statewide Housing Condition

- Mean household unit – 1,507 square feet
- Median household unit – 1,300 square feet
- Average sq ft per resident (mean) – 634
- Average sq ft per resident (median) - 500
- No running water – 10 %
- Trouble maintaining temperature – 26 %
- Drafty – 44.7 %

Source: AHFC 2005 Alaska Housing Assessment

Housing Findings

- % of older housing (21+ years) increasing
- % of new housing (0-10 years) decreasing
- Average cost of single-family unit by region ranges from $172k to $266k
- 45,000 households estimated to be income eligible for weatherization services

Source: AHFC 2005 Alaska Housing Assessment

Statewide Housing Need

- More than 25,000 new housing units needed
- Cost to replace units that are substandard and not salvageable is **$873 Million**
- Cost to alleviate overcrowding for homes with 200 square feet or fewer per resident is approximately **$4.78 Billion** dollars
- Total cost to replace, repair and alleviate crowded conditions is **$5.99 Billion**

Source: AHFC 2005 Alaska Housing Assessment

1326

Shorter Shipping Distances

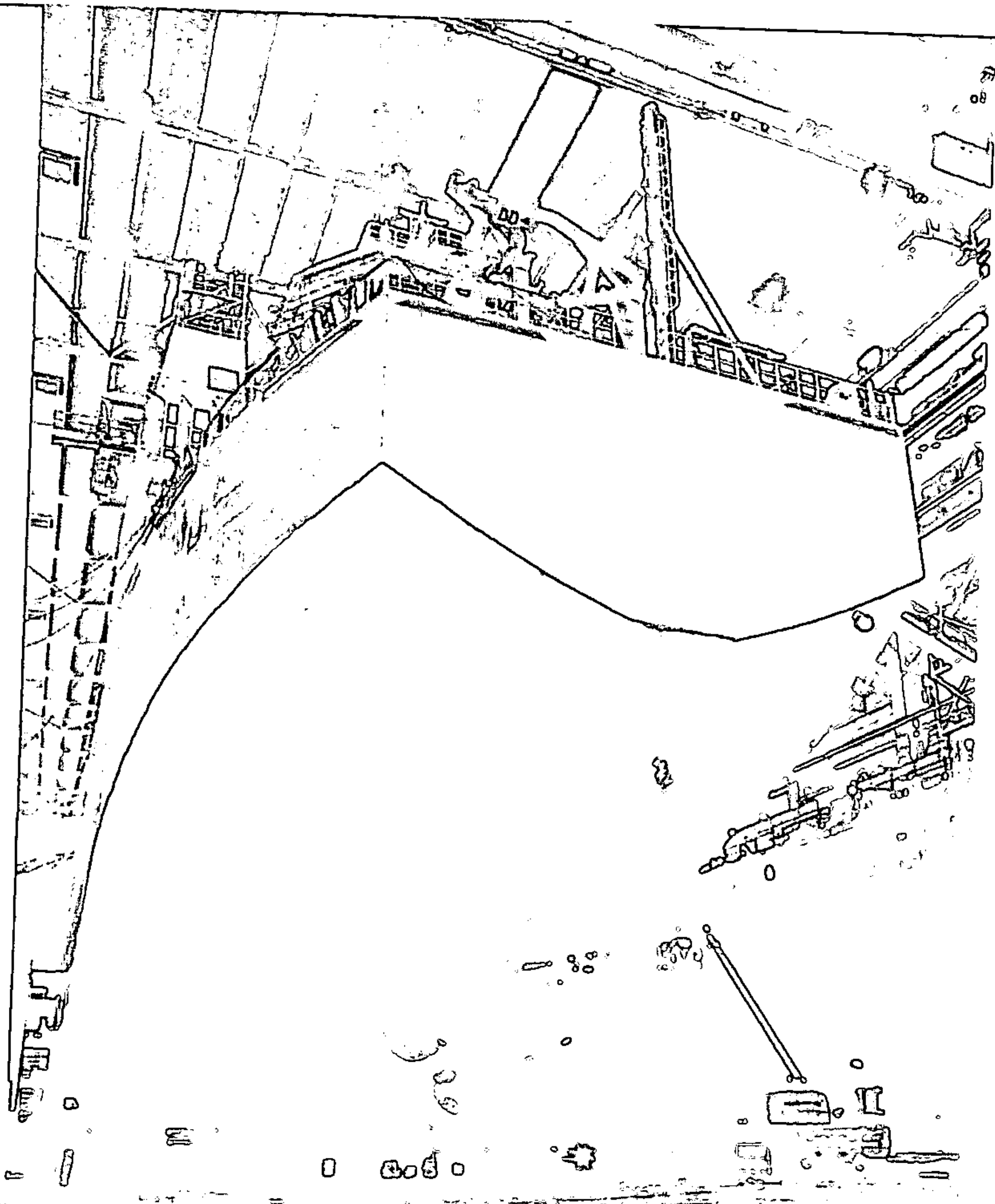
Distance: Hamburg to Yokohama (nautical miles)

Northern Sea Route ~ 6,920

Suez Canal ~ 11,073

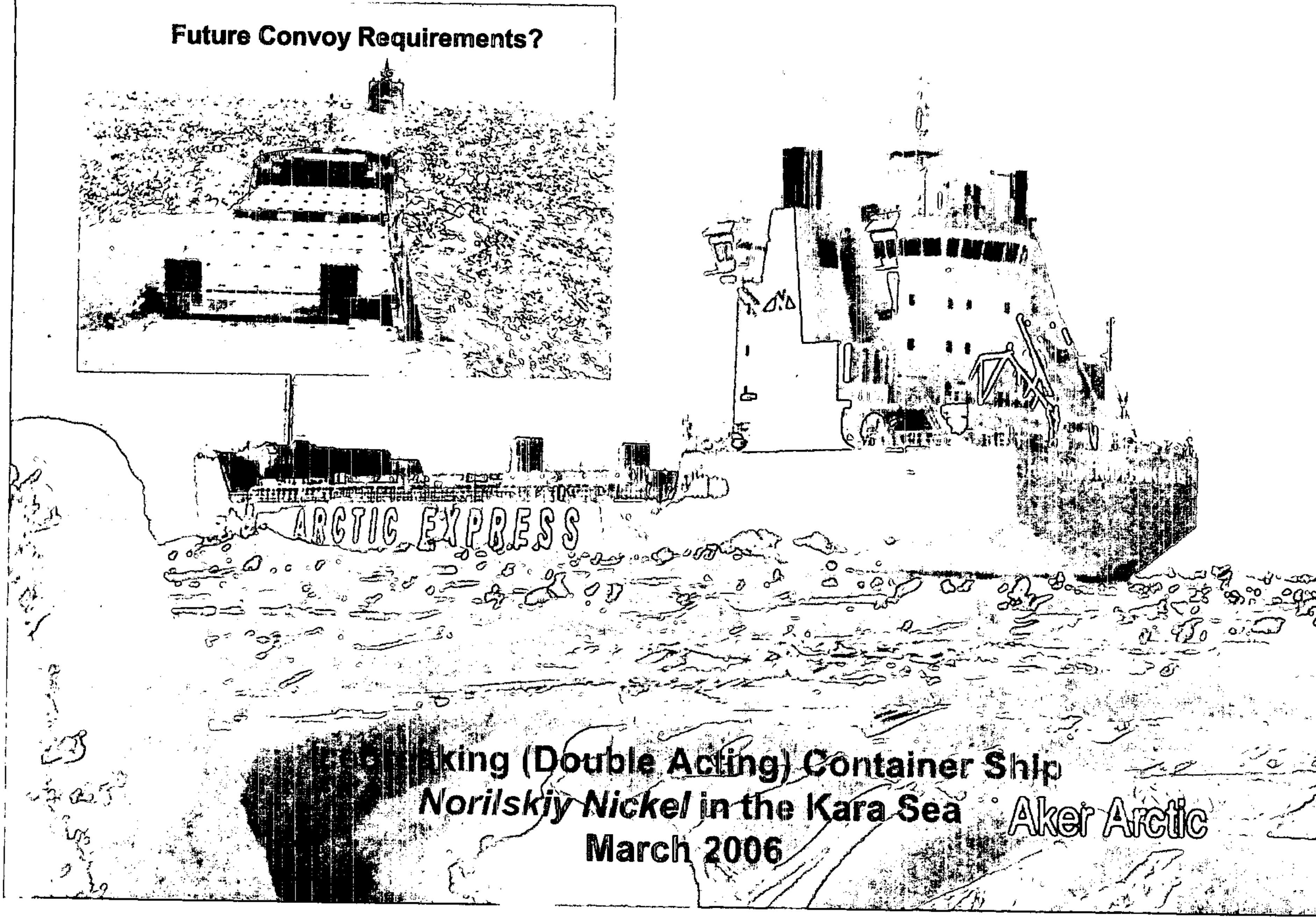
Panama Canal ~ 12,420

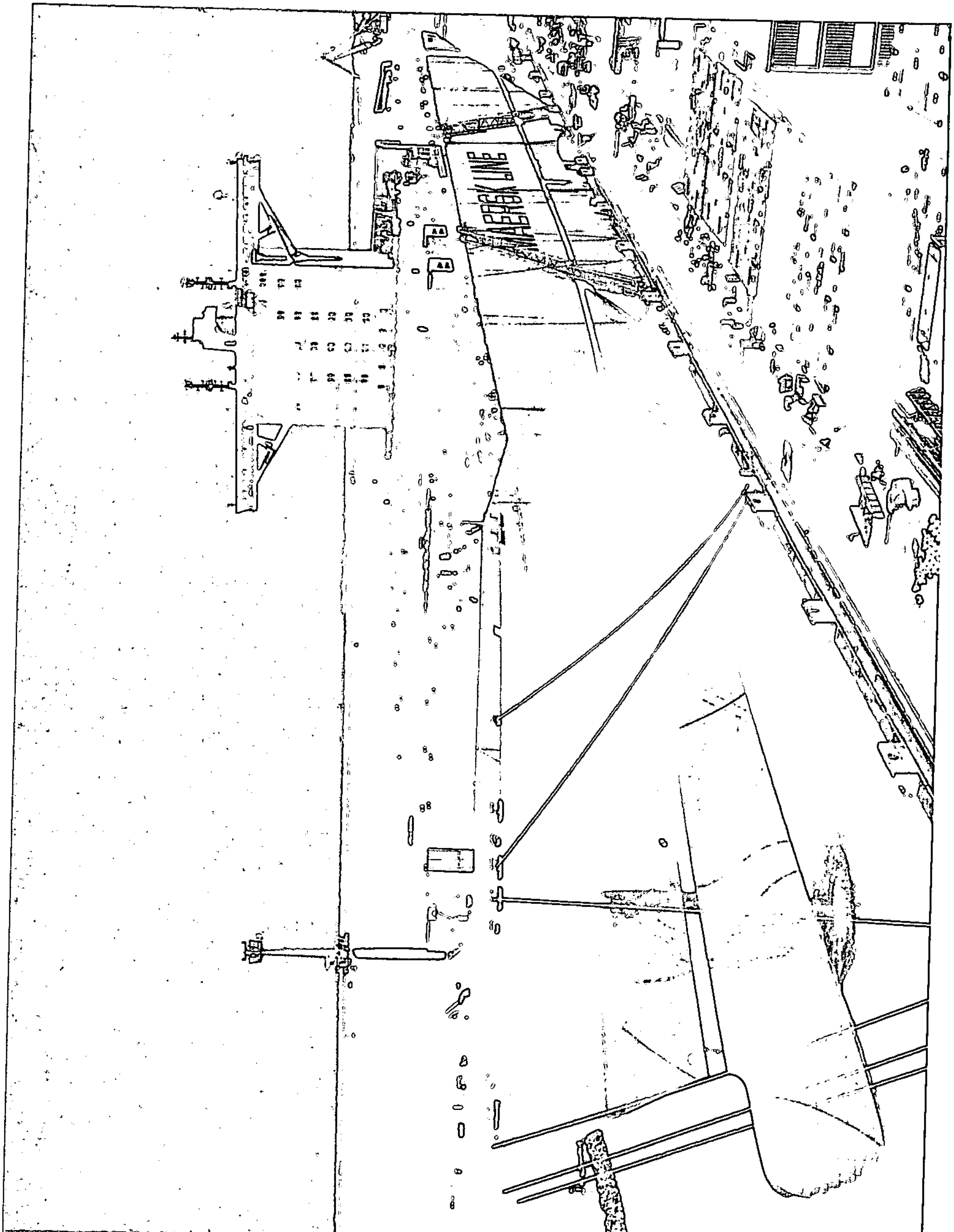
Cape of Good Hope ~ 14,542



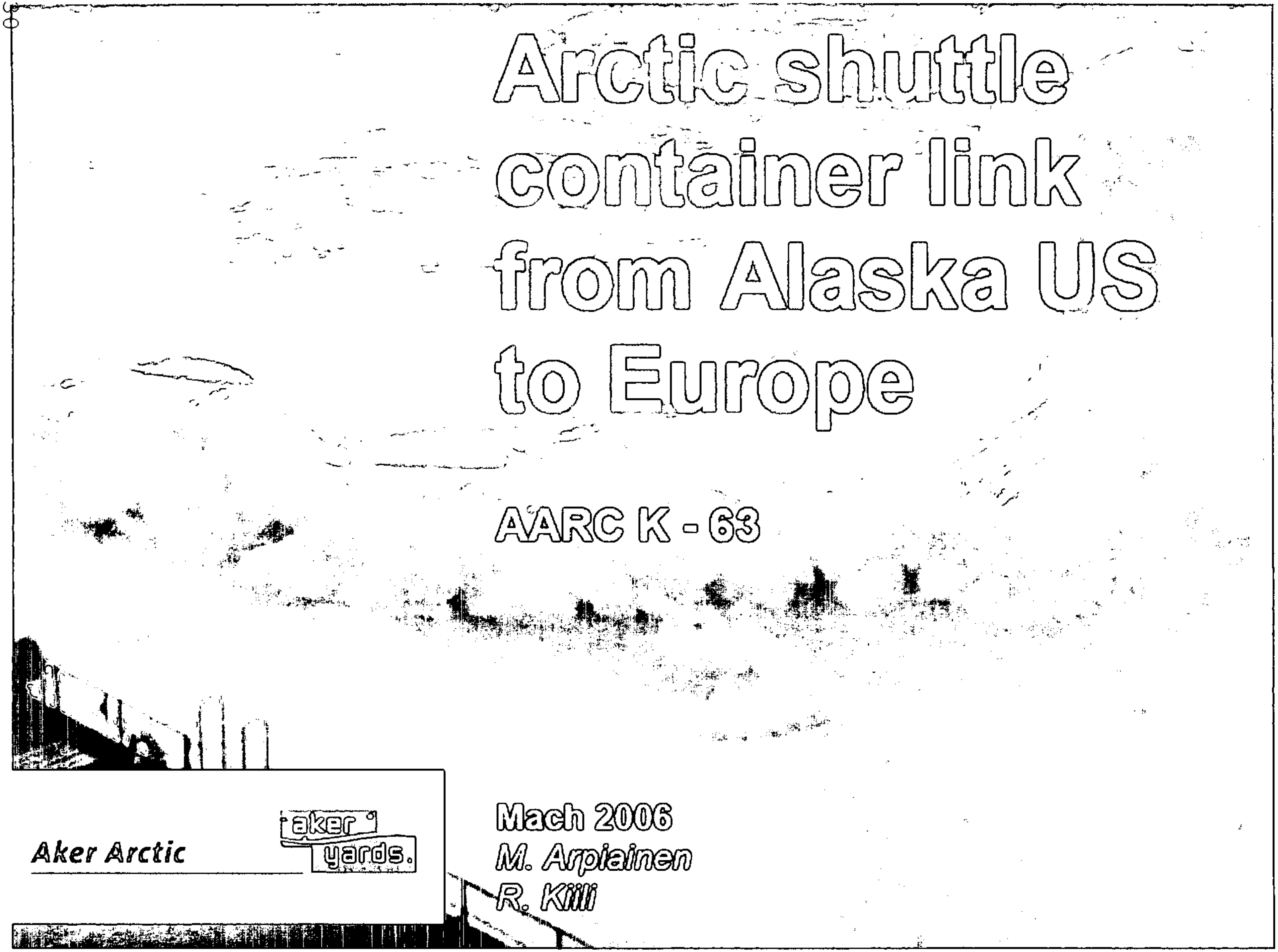
Aker Arctic
Technology

Icebreaker Design for Greater Efficiency




MAERSK LINE

1330


Arctic shuttle container link from Alaska US to Europe
AARC K - 63
Mach 2006
M. Arpiainen
R. Kiili
Aker Arctic
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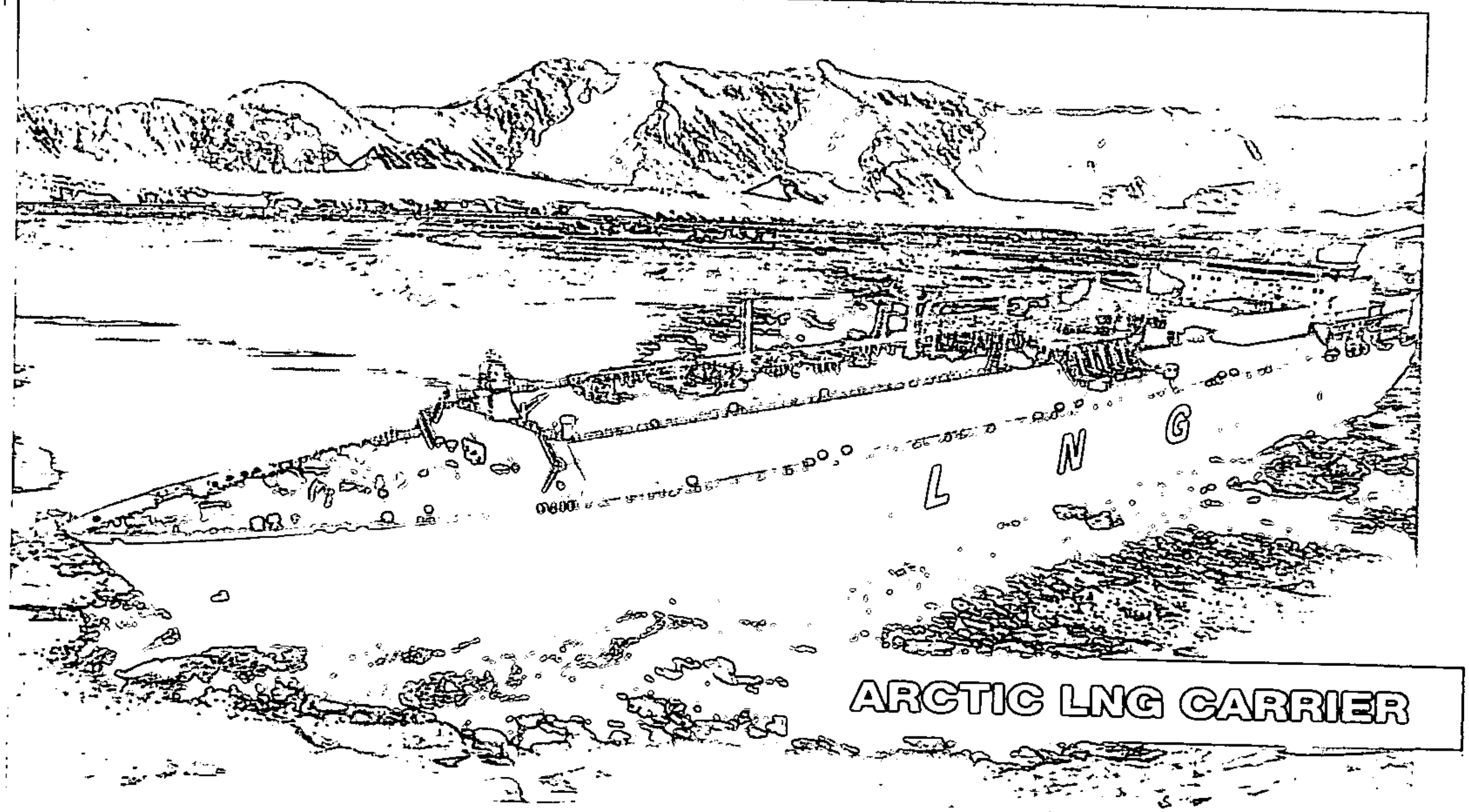
1331



ARCTIC LNG CARRIER OVERVIEW

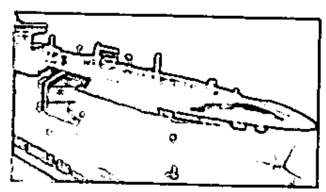
• Ice Class	Baltic Ice 1A / RMRS LU4
• Winterization	Extreme Low Air -40 C
• CCS	Reinforced Mk-III, Combi. or SPB
• Trading Route	Russia/Baltic Sea – USA/Europe

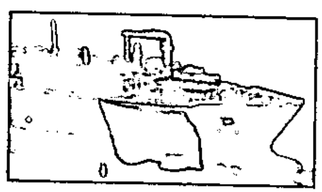
HULL FORM & PERFORMANCE VERIFICATION

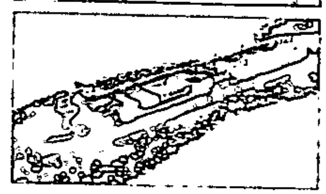
- Ice Collision Dynamic Motion Analysis & Test
- Sea-keeping Analysis under harsh condition
- Speed in Ice and Open water

RELIABLE STRUCTURE DESIGN

- Structural Safety Assessment with Krylov
- Cargo Containment System Safety Assessment with GTT
- Ice Collision Simulation & Test







So

He

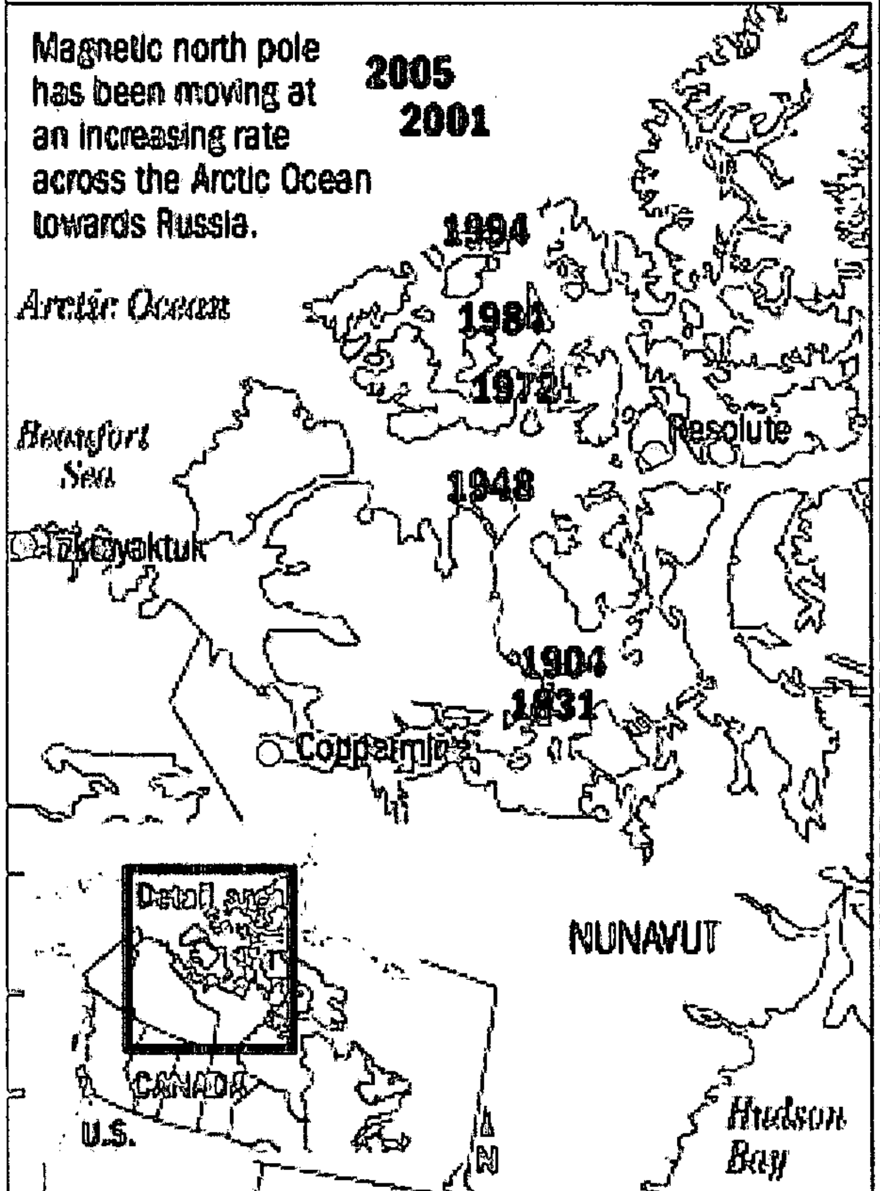
1332

USARC ECUMENICAL BELIEF

- The United States must maintain its global maritime capability—as a government AND as a Nation
- If the U.S. does not exercise its visible maritime presence in the Arctic Ocean—we cede it to whomever wants it!

UNITED STATES ARCTIC RESEARCH COMMISSION

Shifting magnetic north pole



CHARLES ATKINS / Anchorage Daily News

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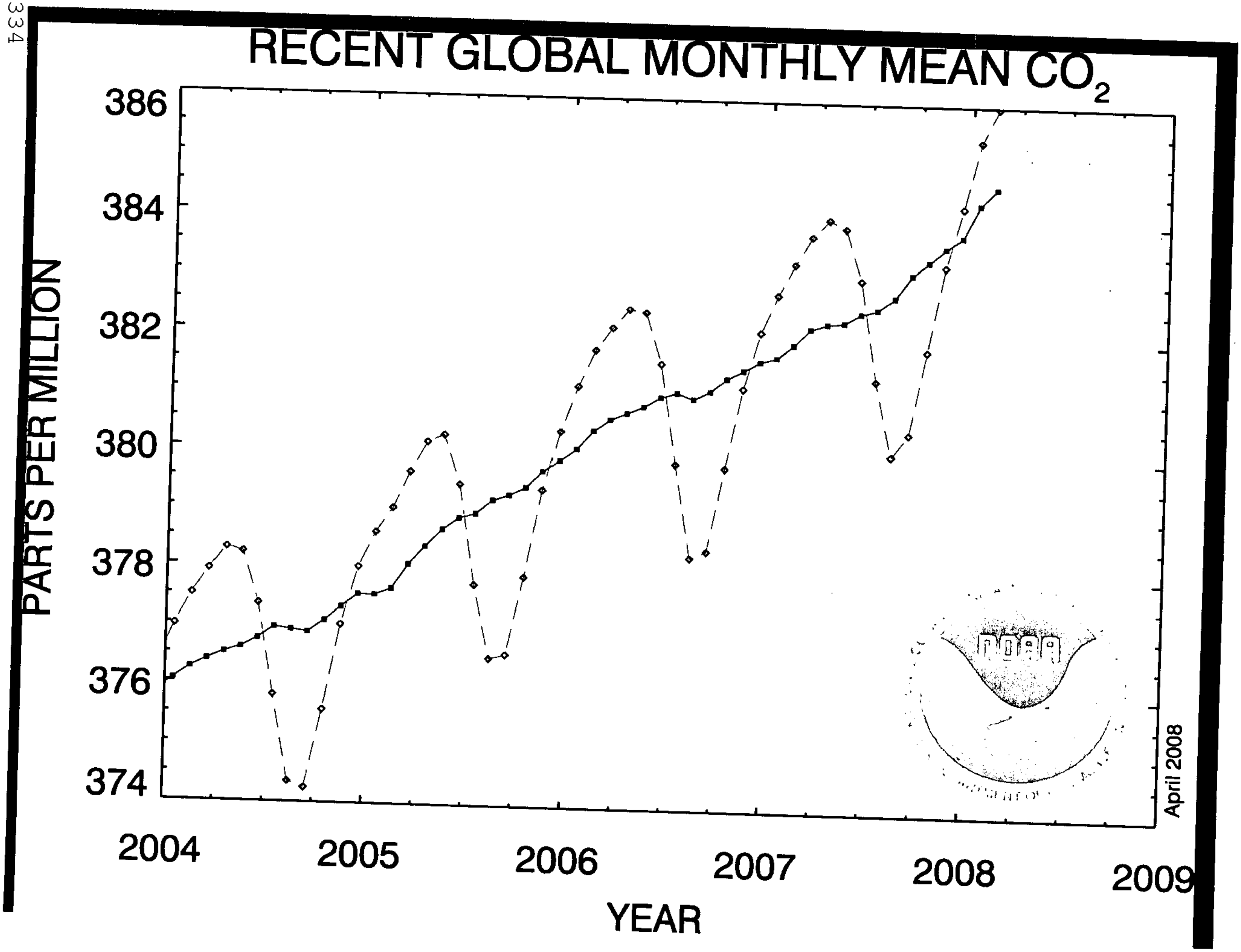
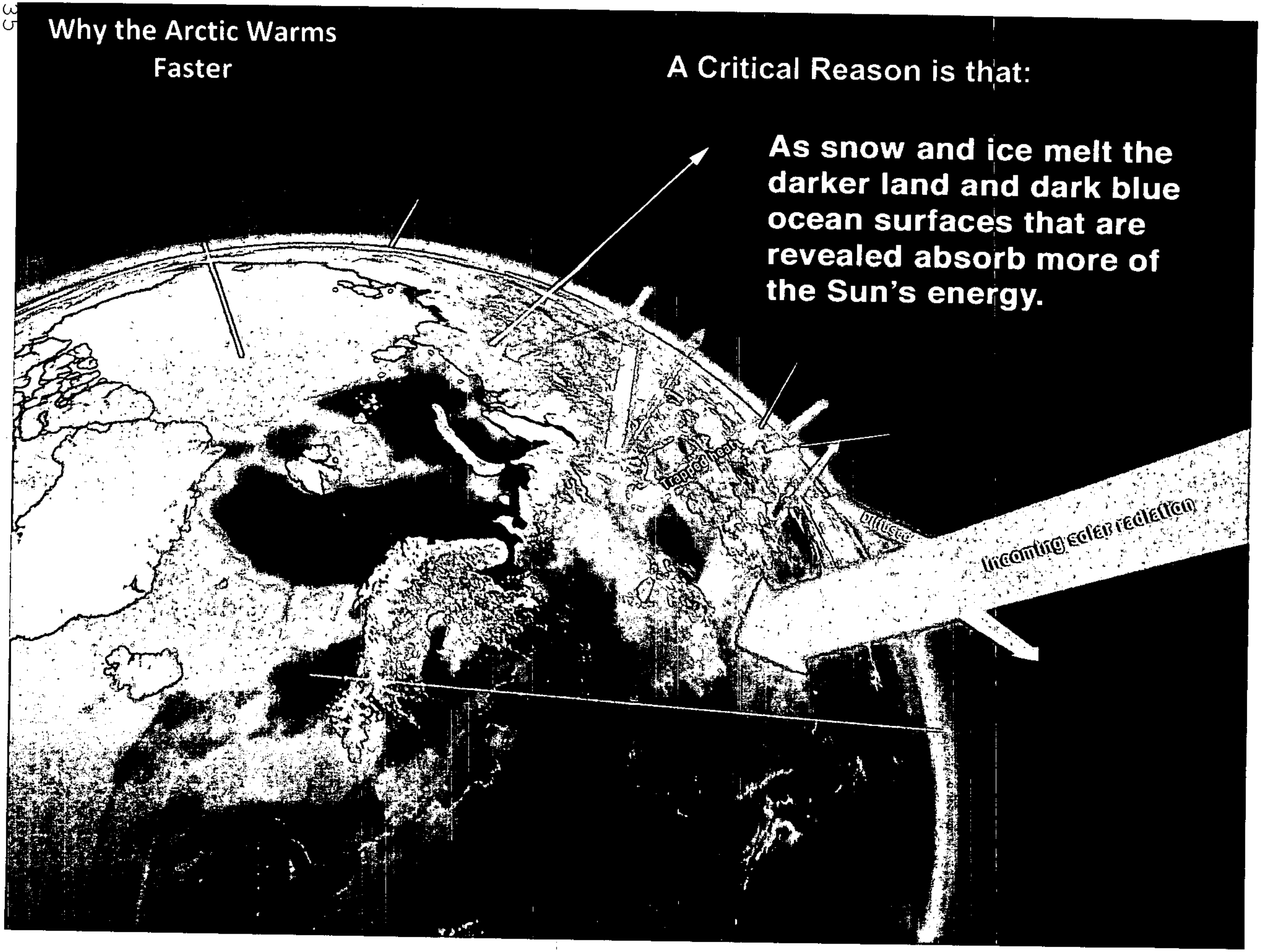


RECENT GLOBAL MONTHLY MEAN CO_2
PARTS PER MILLION
386
384
382
380
378
376
374
2004
2005
2006
2007
2008
2009
YEAR
April 2008

1335


Why the Arctic Warms Faster
A Critical Reason is that:
As snow and ice melt the darker land and dark blue ocean surfaces that are revealed absorb more of the Sun's energy.
Trapped heat
Incoming solar radiation

To Polar Explorers, Godspeed!

http://www.ipy.org

www.arctic.gov

www.us-ipy.org

www.us-ipy.gov

UNITED STATES ARCTIC RESEARCH COMMISSION

www.arctic.gov

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www.institutenorth.org

INSTITUTE OF THE NORTH

Why the Arctic Matters:

The Potential Contribution of Arctic Research to U.S. Climate Change Mitigation Strategy

A report submitted to the U.S. Arctic Research Commission

February 2008

Prepared by

Sarah Dewey

and Dan Wilson

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Introduction

There is now a wide consensus in the scientific community that this century will see average global temperatures rise by anywhere from 1.1° to 6.4° C.[1] That will be in addition to the 0.6° C rise during the last century.[2] Within the past decade, it has become increasingly clear that this warming trend is largely attributable to human activity, especially the burning of fossil fuels (which provide roughly 80% of the world's energy) and the associated release of carbon dioxide and other greenhouse gases into the atmosphere. There is also a consensus that this warming, along with other climatic changes, will have earlier and more pronounced impacts in the polar regions of the Earth than in almost any other region.

The effects of climate change in the Arctic will be complex and far-reaching, affecting an enormous range of human activities, plant and animal species, and Earth systems. These effects will also extend well beyond the current century. Because greenhouse gases remain in the atmosphere for centuries after they are emitted, humans will be dealing with the consequences of climate change for generations. But it is not merely a future prediction; in fact, the impacts of climate change are already being felt all around the Arctic. Some of the current trends and expected future effects discussed in the 2004 Arctic Climate Impact Assessment (ACIA)[3] are:

- The melting of Arctic snows and ice, which decreases the reflectivity of the Earth's surface and contributes to warming, and also causes rising sea levels
- The decline of various animal species that depend on sea ice in the Arctic Ocean (such as polar bears and seals) or on stable frozen tundra (such as caribou)
- The thawing of permafrost, which endangers human infrastructure like buildings and roads, and will likely release large amounts of methane trapped in the soil that will exacerbate warming
- The increasing vulnerability of coastal communities to erosion, as a result of sea level rise and more powerful storms
- The opening of new trans-Arctic shipping routes through the Northern Sea Route and the Northwest Passage, and increasing access to undiscovered oil and gas resources
- Serious challenges to the survival of many indigenous cultures, in the face of diminishing traditional food resources and a more unpredictable environment

[1] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: Synthesis Report Summary for Policymakers*. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf.
[2] IPCC, *Climate Change 2007*.
[3] ACIA, *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. Cambridge University Press, 2004. http://www.amap.no/acia/

It is vital that the future plans of the United States and other Arctic nations address the difficulties and opportunities presented by Arctic climate change—not only because of their stake in the Arctic region, but because climate change in the Arctic has important consequences for the rest of the world. Melting snow and ice, thawing permafrost, new shipping routes and hydrocarbon sources, along with a host of other effects, will reverberate globally.

According to the Intergovernmental Panel on Climate Change, human efforts to mitigate climate change can make a significant difference in the rate and degree of warming, and thus minimize the accompanying negative impacts of climate change.[4] The U.S. Arctic Research Commission (USARC) requested this paper in order to begin a discussion on the potential contributions that the U.S. Arctic Research Program may make to the nation's efforts to mitigate climate change. The U.S. Arctic Research Program has already established an interagency effort, the Study of Environmental Arctic Change (SEARCH), to track climate change – and that effort is being bolstered with the creation of an Arctic Observing Network. The nation has another Arctic research goal – infrastructure research – to provide adaptation tools. Some of the new research directions discussed in this paper would fit well within those two goals. USARC may decide to include some of the new research directions included here in the 2009 Goals Report, and the Interagency Arctic Research Policy Committee (IARPC), which carries out the nation's Arctic Research Program, may decide to pursue this research.

The nation's current climate change mitigation program, which is organized under the Climate Change Science Program (CCSP) and the Climate Change Technology Program (CCTP), was developed by the Committee on Environment and Natural Resources of the National Science and Technology Council (NSTC). Though the mitigation program currently in effect through CCSP and CCTP is a solid beginning, it was not designed with the issues and concerns of the Arctic solely in mind. This paper could be used to enhance the current mitigation program and eventually develop a program that makes full use of the Arctic both as a research venue and as a testbed for mitigation technologies.

This paper identifies six areas in which the Arctic may play a major role in U.S. mitigation strategy:

1) **monitoring of climatic shifts, to support modeling of global effects and accounting for global sequestration strategies**
2) **understanding and protection of natural carbon sinks**

[4] IPCC, *Climate Change 2007.*

3) **modification of point-source energy production methods**
4) **energy conservation and efficiency measures**
5) **methane hydrate research and carbon capture and storage technology**
6) **Geoengineering schemes which take advantage of natural features in the North**

Given that Alaska consumes more energy per capita (and therefore causes more per capita emissions) than any other state,[5] federal investments in mitigation strategies in Alaska may produce more significant carbon emission reductions than equivalent investments elsewhere. Alaska Governor Sarah Palin's recent announcement that the state will set aside $250 million for renewable energy funding, along with her establishment of a Climate Change Sub-Cabinet and appointment of a state-wide Energy Coordinator, indicates that Alaska is ready to move on climate change issues and that federal agencies may benefit from partnering with the state. In addition, a large number of organizations in Alaska are working toward a more sustainable future in various ways, many of which would be valuable partners as well. Many of them are mentioned throughout this report.

Outline of the Report

This paper begins by explaining what is currently known about the Arctic carbon cycle and the processes of Arctic warming. It then describes a rubric that was used to evaluate various mitigation strategies that have the potential to take advantage of unique conditions in the Arctic. Evaluations of the particular strategies follow after that.

- In the first evaluation section, on monitoring, the global need for more widespread and better-integrated Arctic monitoring systems is discussed, and goals for further research are laid out.

- The second section—on natural carbon sinks—reviews the current scientific knowledge of boreal forests, peatlands, permafrost, and their roles in the Arctic carbon cycle. It also considers how management of these sinks could aid in expanding carbon sequestration.

- The third section covers non-fossil fuel energy sources available in the Arctic, or to Arctic residents seeking to stabilize costs and reduce greenhouse gas output: geothermal power,

[5] DOE Annual Energy Report 2007.

hydroelectric power, wind power, solar power, wave and tidal and osmotic power, biomass power, power from hydrogen and fuel cells, and nuclear power.

- The fourth section examines various measures that can be applied to aid energy conservation and to increase energy efficiency. These include: personal- and community-level responses to climate change, "smart grid" technologies, combined heat and power systems, and better building design and building practices.

- The fifth section discusses carbon capture and storage and the extraction of methane hydrates, both of which have the potential to mitigate human carbon emissions while taking advantage of the existing infrastructure and technology of the oil and gas industry.

- Finally, the sixth section describes three different theoretical "geoengineering" schemes—solar shielding, expulsion of particulates, and iron fertilization. Research on these schemes might be able to present solutions the Arctic region can provide to the rest of the world in an attempt to prevent catastrophic global warming.

The Conclusion discusses the importance of responding effectively to climate change, and the critical role that the Arctic can play in the national mitigation strategy. The final section recommends future Arctic research projects.

This paper does not address the current policy debate facing a world which has stated its intent to reduce greenhouse gases to reverse climate change trends. The choice of incentives to cut carbon emissions efficiently –such as subsidized technology, carbon taxes, or a so-called cap-and-trade program for carbon emissions – is beyond the scope of this paper and of the Commission's mandate.

To be clear, all of the mitigation schemes discussed in this paper deal primarily with means to reduce or sequester carbon generated in commercial energy production; carbon emissions from industrial agriculture, transportation or domestic use are not accounted for in many of the scenarios covered. Some mitigation schemes, however, deal with carbon generally. For a complete (though not Arctic-specific) discussion of carbon mitigation technologies, see Field and Raupach, eds., *The Global Carbon Cycle.*[6]

[6] Christopher Field and Michael R. Raupach, eds. *The Global Carbon Cycle.* Scientific Committee on Problems of the Environment, 2004, p108.

Adaptation research,[7] including infrastructure research, is already included in the nation's Arctic Research Plan, and will not be covered here.

Another clarification: "carbon", as used in this paper, refers not merely to carbon in its elemental form, but to any number of (generally gaseous) carbon compounds. Primary "carbons" discussed here are carbon dioxide (CO_2) and methane (CH_4). Both of these are greenhouse gases, but methane's global warming potential (GWP) is far higher than that of CO_2.[8]

[7] For a discussion of the philosophy of adaptive response to climate change, see the Pew Center on Global Climate Change's document "Coping with Global Climate Change: the role of adaptation in the United States" (Easterling, Hurd, and Smith, June 2004).
[8] Reay, Dave. The Encyclopedia of Earth, 2007: www.eoearth.org/article/Greenhouse_gas.

The Carbon Cycle in the Arctic[9]

The Arctic carbon cycle consists of two main components: the terrestrial and the aquatic. The terrestrial carbon cycle works through several processes. Plants take in carbon through photosynthesis; with the death and decay of plants and animals (or by their respiration), carbon is released back to the atmosphere. Geographic weathering may also reintroduce carbon into the cycle through the oceans. The combustion of fossil fuels for transportation and energy and industrial agriculture, the production of cement, and volcanic eruptions all introduce carbon into the atmosphere.

The aquatic carbon cycle, which is not isolated by any means from the terrestrial carbon cycle, has within it two distinct cycling systems. Carbon enters the ocean through both a "solubility pump" and a "biological pump". The term "solubility pump" describes the mechanism by which atmospheric carbon dissolves in ocean water. The cooling of water near the poles increases the amount of carbon-based gases that can be dissolved in it. As the water cools, it becomes denser and sinks, producing a circulation through which carbon is carried down into the deep ocean. The "biological pump" occurs as sinking particulates such as exoskeletons (made of calcium carbonate) and fecal matter deposit carbon in the deep ocean. The same upwelling that drives the solubility pump cycles this organic carbon through the ocean.

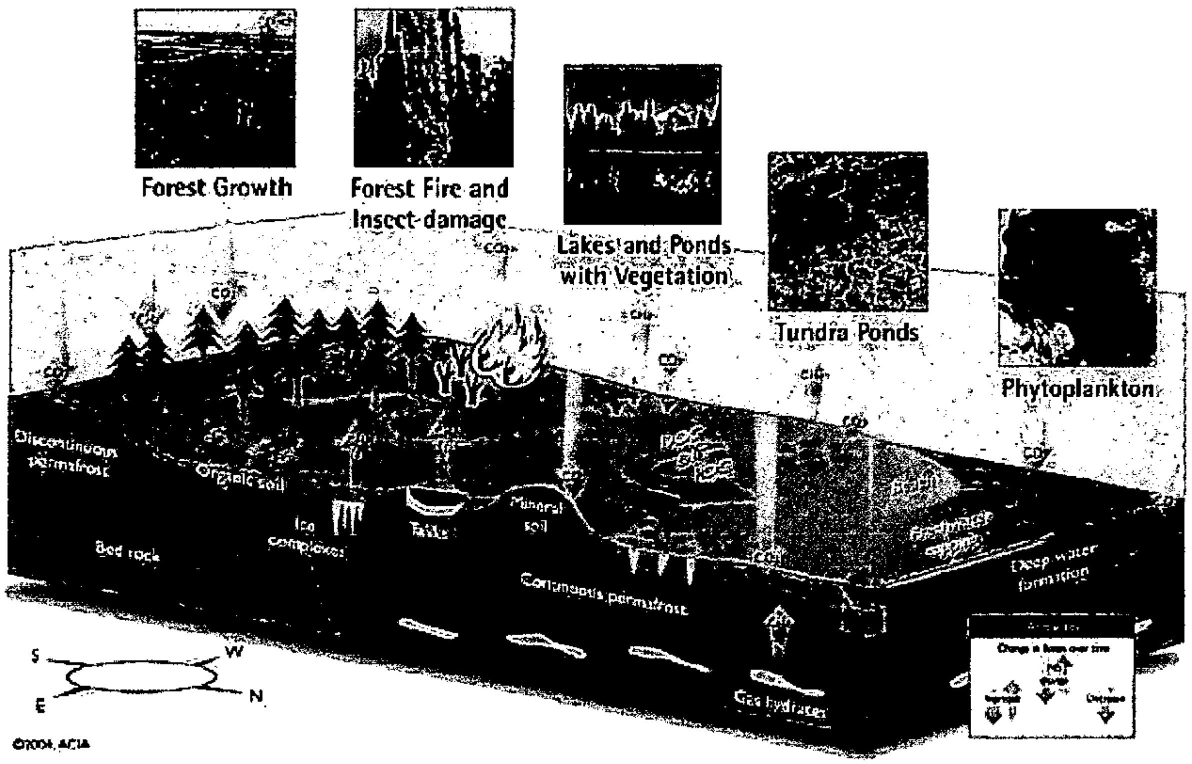
Both the geology and ecology of the Arctic play a role in the region's carbon cycle. Much of the Arctic lies in zones of high seismic and volcanic activity, which are often associated with high rates of natural geological CO_2 emissions. Permafrost and peat, distinctive Arctic soils, act as a storage place for carbon, primarily in the form of methane. Boreal forests, or taiga, also sequester large amounts of carbon.

Though many scientists have investigated the process, the mechanics of the Arctic carbon cycle remain largely a mystery, and many believe that "unlocking" the carbon cycle is the most important step in advancing future mitigation science. A number of further studies on the cycle are currently underway. For example, the American Geophysical Union (AGU), inspired by the completed Arctic Climate Impact Assessment, is now conducting an Arctic Carbon Cycle Assessment.[10] The National Science Foundation-led, USARC-inspired SEARCH program maintains monitoring stations throughout the Arctic, most notably at Toolik Lake and Barrow in Alaska, which continuously gather data on the cycle. The

[9] Please see Figure 1, on page 4 of this report.
[10] Heyes et al, "Supplemental Material to 'A Scientific Synthesis and Assessment of the Arctic Carbon Cycle'", 2007. http://www.agu.org/eos_elec/2007/26-270.html

University of Montana is also engaged in its own assessment of the Northern Carbon Cycle (through freeze-thaw periods) and a monitoring program.[11]

The Arctic Carbon Cycle



(Image courtesy of ACIA)

[11] Kimball, J.S., Northern Carbon Cycle project. www.umt.edu/flbs/Research/NCC.htm

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A Rubric to Evaluate the Possibilities

The technologies and measures discussed in this paper run the gamut from passive monitoring to active management, and from relatively cheap to very expensive. A rubric follows, through which the potential benefit of each option may be ranked. However, in any carbon management plan in the Arctic, as in the globe, it is likely that one solution is not sufficient—mitigation strategies will likely be assembled into a comprehensive "portfolio" for addressing climate change.[12] Each mitigation strategy shall be evaluated under the following criteria, with attention to economic efficiency and feasibility. A few of the mitigation strategies included merit a brief discussion, but not a full analysis using these categories, and those sections will be shorter. For some other strategies, certain portions of the rubric are not applicable—for instance, most renewable energy sources have essentially no feedback problems—and will not be discussed.

Further Research & Development Needs (R&D)- Some of these technologies, such as carbon capture and storage and wind power, are well-established and tested; others, such as geoengineering, remain purely theoretical. This section of the rubric projects a future course for the development of each mitigation strategy.

Infrastructure Needs- As with the research and development section of the rubric, this portion describes what infrastructure is already in place and what needs further development for various technologies. For example, monitoring is an area in which further infrastructure must be established, because today's in-situ measurement stations are sparsely located.

Implementation Costs- This section serves as a rough estimate, before accounting for feedback, of the cost of future R&D, infrastructure development and deployment of the strategy. Implementation "costs" are derived from theory, from practice, and sometimes from government organizations' budget information. Explanations of why the costs might be at such levels are included.

Geopolitical or Cultural Considerations- Because the Arctic is part of the global commons, with territory owned by many—or all—nations, deploying effective carbon mitigation schemes may require international cooperation. This portion of the rubric will speak to the role of cooperative mechanisms, and in some cases consider impact on Native communities.

[12] Field and Raupach.

Feedback Issues- Climate change begets further climate change. The greenhouse effect works as a feedback cycle and the world is now witnessing a snowballing of feedback cycles in the Arctic. Even if a technology appears to address a surplus in carbon, there is a chance that the technology could somehow add carbon back to an earth system or increase warming in other ways. Thus, some strategies may not be as effective as projected. For this reason, feedback cycles affect the cost and timescale of different mitigation strategies.

Feedback has four subsets: albedo, GHG uptake or emissions, GHG emissions from methane hydrates, and increased freshwater fluxes which could affect thermohaline circulations in the world's oceans.[13] All carbon mitigation schemes will be examined through these four lenses, on which various scientists as well as the authors of the ACIA have agreed. Albedo, the only feedback mechanism not directly involving carbon, is the ratio of reflected to incident light; an albedo of 1 means that all light is reflected, while an albedo of 0 means that all light is absorbed. Greenhouse gas uptake or emission describes whether an entity acts as a source or sink of those gases, and GHGs from methane hydrates are included because of the hydrates' propensity for escape and the relative global warming potential (GWP) of CO_2 and CH_4. Increased freshwater fluxes result from melting ice and from altered ocean oscillations. All of these feedbacks exacerbate each other, since warming from gases may encourage release of more gases, for example.

Timescale- This portion of the rubric describes how quickly various mitigation schemes might be deployed. Of course, this can shift depending on pressures or initiatives from interest groups.

Federal Programs- This section will detail the current federal research programs and initiatives that are relevant to each mitigation strategy. These will often fall under the umbrella of either the CCSP, which coordinates federal research programs in a number of departments and agencies that are related to understanding the processes and impacts of climate change, or the CCTP, which coordinates federal research programs related to development of a host of climate change mitigation technologies—ranging from nuclear fission to solar panels to electricity grid upgrades. However, there are other departments and agencies that have established relevant programs, and these will be included as well. In the first two sections, on monitoring and carbon sinks, and in the section on methane hydrates and carbon capture and storage, this segment of the rubric will be integrated into the other segments.

[13] Callghan et al, "Climate Change and UV-B Impacts on Arctic Tundra and Polar Desert Ecosystems", Key Findings and Extended Summaries, 2004. http://www.bioone.org/perlserv/?request=get-document&issn=0044-7447&volume=033&issue=07&page=0386. Also, see ACIA, p. 315.

Short- and Long-term Benefits- These sections illustrate how effective a technology might be on a long or short timescale. They help weigh the costs and the feedback mechanisms when evaluating a technology. Some carbon "solutions," such as stratospheric spreading of particulates, are only effective in the short-term, while others, such as boreal forest and permafrost sinks, are likely to sequester carbon for long periods of time.

Mitigation Schemes the Arctic Research Program May Consider

A matrix is presented here that summarizes the results of applying the rubric described above to each of the possible mitigation strategies. A detailed discussion of each mitigation strategy then follows, which supports the results included in the matrix.

Mitigation Scheme	R&D Needs	Infrastructure Needs	Implemen-tation Costs	Geopolitical or Cultural Considerations	Feedback Issues	Timescale	Federal Progams	Short- and Long-Term Benefits
Enhanced Monitoring	In-situ and remote sensing monitoring systems	Integrated monitor-ing systems—e.g. the AON	Propor-tional to the extent of the program	Will require inter-national collabor-ation	N/A	Techno-logy available today, but will take time to imple-ment	Partner-ships: OCO, GCOS, GEOSS; CCSP	Increased carbon emissions accountability; better understanding of climate changes
Boreal Forests	Understand-ing of nutrient and feedback cycles; fire manage-ment strategies	Systems for monitor-ing of forest cycles and fire suppre-ssion	Propor-tional to the extent of monitor-ing and fire suppre-ssion efforts	May cause inter-national impacts, and require inter-national collabor-ation	Complex, and not fully understood; fires may either help or hinder carbon sequestra-tion	Forest research and manage-ment is ongoing	BLM Alaska Fire Service; CCSP	Forest management may enhance this important carbon sink in the long term
Peatlands and Permafrost	Understand-ing of feedback cycles; marginal potential of peat as a fuel	Monitor-ing systems and strength-ening of civil infrastruc-ture	Propor-tional to the extent of monitor-ing and infrastruc-ture strength-ening	Soils are important to local ecosys-tems and local peoples	Warming may cause large GHG emissions	Ongoing research and develop-ment of infrastru c-ture	DOI's perma-frost monitor-ing network in northern AK; CCSP	Management may enhance this carbon sink in the long term
Geothermal Power	Exploration and drilling technology; EGS systems; transport	Infrastruc-ture for drilling, explora-tion and transport	High start-up costs and low costs thereafter	Reduces depen-dence on imported fossil fuels	Negligible emissions; may actually reduce atmospheric carbon	Currentl y available ; needs funding	DOE prog-rams, e.g. GeoPow ering Amer-ica; CCTP; federal PTC	Local, reliable energy source; reduces carbon emissions

Hydroelectric Power	Studies of micro-hydro feasibility in rural Arctic; cold climate issues	Transmiss-ion capacity	High initial costs	Clean, domestic energy source	No carbon emissions, but can have other significant environ-mental impacts	Currentl y available ; possible long lead time	DOE EERE's Wind and Hydro-power Techno-logies Program	Local, reliable, renewable source of base-load power
Wind Power	Energy storage; wind-diesel hybrid systems; coupling with hydrogen production	Wind-diesel hybrid systems; local wind energy infrastruc-ture	High initial costs; in rural Arctic, high shipping and other costs	Can provide starting point for rural commun-ity energy plans	No carbon emissions, but possible minor environ-mental impacts	Currentl y available and growing quickly	DOE EERE's Wind and Hydro-power Techno-logies Prog-ram; CCTP; federal PTC	Renewable energy source; only hampered by intermittency issues
Solar Power	Solar power coupled with other renewable energy sources	N/A	Not feasible on a large scale in the Arctic	N/A	None	May become more cost-effective in the future	Various DOE prog-rams; CCTP; federal PTC	May provide reliable power when coupled with other renewable sources
Wave, Tidal and Osmotic Power	Further demonstra-tion of wave and tidal technology; feasibility study of osmotic power	Energy transport for wave power; greater funding and produc-tion incentives	High initial costs	N/A	No emissions; possible minor environ-mental impacts	May become compete -tive within a decade	Small amount of DOE R&D funding	Denser and more predictable energy source than wind or solar
Biomass Power	Feasibility studies of various biomass options; demonstra-tion projects	Local biodiesel capacity; landfill gas extraction; CHP systems	High initial costs in some cases	N/A	Small emissions relative to fossil fuels	Currentl y available ; ongoing develop-ment	Various DOE and EPA prog-rams; CCTP; federal PTC	Reduces carbon emissions and extracts energy from waste

Hydrogen and Fuel Cell Technology	Development of nearly all aspects of the technology; e.g. wind-hydrogen demonstration project	Large-scale replacement of energy infrastructure	Enormous costs for both development and implementation of "hydrogen economy"	Requires significant international cooperation (e.g. IPHE)	Depends on how hydrogen is produced	No significant impact for a decade or more	DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program; CCTP	Clean fuel source; possible clean energy storage and transport medium
Nuclear Power	New reactor types; efficiency improvements	Nuclear waste disposal	Very high initial costs	Citizen opposetion and potential for nuclear proliferation	No carbon emissions; environmental concerns because of nuclear waste	Currently available; can take ten years to build a new plant	Various DOE programs; CCTP	Widely accepted non-fossil energy source without carbon emissions
Personal Conservation and Community Planning	Research on current awareness and ways to conserve, and on better community planning practices	Education campaigns; central information source; community plans	Very few costs; costs are usually repaid in energy savings	Cooperate with other Arctic nations in developing best practices	Reduces unnecessary energy use and emissions	Immediately available; should be current and ongoing process	Efficiency programs, e.g. Energy STAR	Cheapest way to reduce energy costs and carbon emissions
"Smart Grid" Technology	Feasibility studies; better utility management systems for integrating "distributed generation"	Deployment of technologies, coinciding with upgrade of grids themselves	Depends on the scale of the technology, usually high initial cost	N/A	Increases efficiency	Currently available, or will be available soon	DOE programs; CCTP	Increases efficiency and reduces emissions; increases consumer awareness of energy use
Combined Heat and Power Systems	Feasibility studies; demonstration projects, especially of diesel heat recovery systems	Fuel sources; integration with building; smart grid technology	High initial costs	N/A	Reduces energy use and emissions per unit of fuel used	Currently available	EPA CHP Partnership; CCTP; federal PTC (biomass)	Increases energy efficiency and flexibility of the grid

Building Design and Practices	Development of better design, materials and practices for Arctic buildings; net-zero-energy systems	Implementation of better practices, including education	May be high initial costs	Cooperate with other Arctic nations in developing best practices	Increases efficiency	Currently available; net-zero-energy buildings still expensive	Various DOE programs; CCTP	Increases energy efficiency and creates jobs; reduces long-term emissions
Methane Hydrates	Feasibility studies of stability of methane hydrates and possibility as a fuel source	Infrastructure strengthening	Large costs for at-sea operations	Possible conflicts over ownership of undersea resources	Relatively low carbon emissions compared to other fossil fuels; danger of "blowouts"	Could have significant impact within a decade	DOE; CCTP	Large fossil energy source with low relative emissions
Carbon Capture and Storage Technology	Further demonstrations of CCS technology; research on clathrates, monitoring	Coupling CCS with existing production wells; monitoring systems	Too expensive to implement widely without incentives	Can cause disputes where storage sites cross national boundaries	Reduces emissions directly; concerns about carbon escaping from underground and citizen opposition	Currently available, though expensive; will be motivated by regulation	DOE; CCTP	Reduces carbon footprint of fossil energy production; allows time for renewable energy development
Geoengineering (Solar Shielding and Expulsion of Particulates)	Effects on climate; possible feedback cycles; feasibility studies	Enormous but unclear	Enormous	Very complex negotiations necessary; uneven distribution of gains and losses	Potential for unintentional effects on climate	Not known precisely, perhaps decades	N/A	May avert catastrophic warming in the short term

1) Enhanced Monitoring

Monitoring of carbon levels in the ecosystem is gaining importance as climate change becomes more critical—not only as an indicator of the scope of the planet's warming, but also as a way of increasing emissions accountability under initiatives like the Kyoto Protocol. Especially in the Arctic, the site of the most extreme and rapid climate change, monitoring can help determine sources of greenhouse gases in the atmosphere, in order to guide a global course of action for combating harmful warming. Monitoring is a diverse branch of essential research for carbon mitigation, and must collect data on: 1) atmospheric carbon, 2) soil carbon (which often involves seismic analysis of permafrost and seabed hydrate formations), 3) flux through surface vegetation, and 4) point-source emissions. In addition, it is essential that these data are gathered through an integrated monitoring system in order to generate a comprehensive picture of the Arctic carbon cycle. Because of the influence of other elements on carbon cycling, as well, monitoring of several different nutrient cycles can also give a sense of the extent of the carbon cycle. Understanding and assigning numeric value to this essential yet enigmatic element is a challenge, but one that must be overcome in any effort to curb climate change.

R&D- Carbon monitoring in the Arctic needs to reach an appropriate balance between in-situ recording and remote-sensing, for several reasons. Extrapolation of *in-situ* data points is often inaccurate, while satellite imaging is not detailed enough. Each involves a trade-off: *in-situ* data can give a sense of the soil composition—of extreme importance in Arctic ecosystems especially—while remote-sensing can measure factors like tree cover. Given carbon's role at both the micro- and macro-scale, an integrated monitoring system is an essential aim for further research. USARC has set up a workgroup to define research which will help to better understand the scaling issues.

Infrastructure Needs- The needs for Arctic monitoring infrastructure are huge—and include the development of detailed data collection over a wide area—though they are gradually being addressed through the development of the Arctic Observing Network (AON).[14] Of key importance to the AON is the integration of various international monitoring systems to provide one complete picture of the Arctic environment. Besides the AON, NASA plans to launch the Orbiting Carbon Observatory (OCO) in 2008, which will provide the first-ever data-gathering on atmospheric carbon from space. The U.S. has joined the international Global Climate Observing System (GCOS), which will focus on the Arctic during the International Polar Year (IPY),[15] and also the Global Earth Observing System of Systems (GEOSS)

[14] Information about the AON's needs and goals can be found at http://dels.nas.edu/prb/aon.
[15] *The U.S.Climate Change Science Program for FY2008*, p. 27: http://www.usgcrp.gov/usgcrp/Library/ocp2008/default.htm.

effort, a partnership between nearly 60 countries for coordinating Earth observations which promises to be an important framework for international cooperation on monitoring and management of the environment.[16]

Implementation Costs- The cost of an Arctic carbon monitoring system can be as open ended as the requirements that are established for the system itself. Current IPY awards for AON development total approximately 37 million dollars from FY06 through FY09.[17] While this system will be immensely helpful to future scientific research, many scientists caution that the cost of demonstrating carbon level changes often can exceed the value of the reduction in emissions.[18] Accountability and economy, therefore, drive one another. As nations determine the "costs" of carbon through regulation, carbon tax or market based cap-and-trade schemes, the value of monitoring initiatives will become more apparent.

[16] From the Group on Earth Observations (GEO) website: www.earthobservations.org/.
[17] Martin Jeffries presentation at National Ice Center and USARC Conference, "On the Maritime Implications of an Ice-Diminished Arctic," July 2007.
[18] Field and Raupach, p. 487.

2) Fostering Carbon Sinks

The natural carbon sinks of the circumpolar regions are among the largest in the world. Approximately 13% of the earth's carbon lies in the boreal forest soils, with an additional 14% in tundra soils. This 27% of the Earth's terrestrial carbon is stored within 13%-14% of the Earth's total land area.[19] This large amount of sequestered carbon is cause for concern if its release is part of a warming feedback cycle.

The complexity of Arctic ecosystems presents an obstacle to prescribed mitigation, because the myriad interactions between various molecules and organisms have yet to be fully understood. A scheme aimed only at one natural sink, while it may be helpful, will also be fundamentally insufficient, due to the fact that a sink is part of a larger carbon cycle. Any carbon mitigation scheme involving natural sinks must necessarily examine the other nutrients or microbes involved in the cycle, since without an understanding of these interactions human efforts could potentially impede, rather than facilitate, the functioning of the sinks.

While the Kyoto Protocol stipulates that natural sinks must be preserved and encourages their management to enhance sequestration,[20] direct management of carbon fluxes on Alaska's vast tracts of wild land is probably not feasible. Therefore, research should focus on understanding—and monitoring—nutrient cycling in Arctic tundra and taiga ecosystems. Understanding natural sinks and implementing monitoring systems will help to protect them and also increase accountability for damage to them. Various CCSP-coordinated research activities address the need for understanding Northern forests: the Yukon River Basin research initiative (a comprehensive study of air, water, soil, forests and adjacent ocean in the Basin), the National Land Cover Database (a complete land cover map at 30 meter resolution of the whole U.S., the Alaska section of which was just finished), and advanced carbon modeling of the both the terrestrial and aquatic carbon cycles.[21]

While much research and many resources have been dedicated to managing cropland to work as a carbon sink, this science is not included in this report because it is not yet very applicable to Northern regions, though it may become so with climate change. The extent of, and direction of, agricultural shifts due to climate change are relatively unpredictable: changes in moisture and temperature must balance one another, and an increase in temperature without one in precipitation could threaten Alaskan farming,

[19] J.M. Kimble, ed. "The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect" (2003) Ch. 16, p. 3: www.environetbase.com/books/1040/l1583_fm.pdf
[20] Kyoto Protocol website: http://untreaty.un.org/English/notpubl/kyoto-en.htm.
[21] *The U.S. Climate Change Science Program for FY2008*, pp. 51-52: http://www.usgcrp.gov/usgcrp/Library/ocp2008/default.htm.

while an increase in both could bolster it.[22] It is therefore worth paying attention to cropland management techniques, and worth realizing that they may eventually become relevant in northern latitudes. Techniques for managing grazing land could become appropriate as well, particularly in the northern regions in which reindeer herding is a main source of subsistence, such as the Lapland areas of Fennoscandia.

a) Boreal Forests

The Northern boreal forest, or taiga, is a hugely important carbon storage system, which constantly vies for the title of largest terrestrial carbon sink.[23] Unlike tropical forests, which absorb a greater amount of carbon but hold it for a lesser time, boreal forests hold the carbon they absorb for many years.[24] While much of the ability of the taiga to act as a sink is due to the organic material of its soils, the trees play an important role through respiration and photosynthesis. Current research into the nature of the boreal forest is more diagnostic than anything else. Future research should focus on the interaction between various nutrients and microbes and the carbon cycle, and also on the study of management techniques—especially fire management.

Management of boreal forests requires understanding not only of nutrient cycles, but of stand disturbance cycles. If natural succession or disturbance cycles occur such that carbon storage isn't maximized, then management of the stand can tip cycling in that direction. As disturbance cycles increase (as is the case with frequent fire incidence), then management geared towards suppressing disturbance is effective for carbon storage as well.[25] However, in unmanaged lands with relatively stable disturbance cycles, there is little need to maximize sequestration with management, nor will any human effort do so efficiently, especially with a hazy understanding of how the soil and its nutrients are effected by disturbance cycles.

Fire management is discussed here because it is a practice at which Alaska is old hand. It is an exercise in balancing: forests tend to sequester more carbon as they get older, but also have a tendency to burn and to emit all of that carbon. Managing burns at the correct stage of forest succession can help optimize the amount of carbon sequestered in a forest. Because coniferous trees require fire to release their seeds, total

[22] ACIA, p. 808.
[23] Stephens et al, 2007 "Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO2": www.sciencemag.org/cgi/reprint/316/5832/1732.pdf
[24] Davidson et al, 2000. "Soil Warming and Organic Carbon Content" Nature 408: 789-90
[25] Can. J. For. Res. Vol. 27, 1997 Price et al

fire suppression is not an option for the taiga. But wise fire management can maximize carbon sequestration while promoting the health of the forest.

R&D/Infrastructure Needs- Research on fire management continues to grow, after the 1999 Frostfire Prescribed Burn in which the federal Bureau of Land Management (BLM) Alaska Fire Service set a boreal plot on fire in an effort to study every aspect of taiga burns.[26] While research must continue to develop an understanding of how fire affects nutrient cycling, one of the most important needs for R&D—and indeed, infrastructure—is monitoring. Monitoring need not be constant—in fact, meteorological satellites may be appropriate to detect fires. But closer monitoring of fires could provide insight into the carbon cycle. The Canadian Forest Service releases an annual Fire Research Science Report,[27] and much current boreal forest research centers on the effects of fire on the carbon budget.

Implementation Costs- Monitoring is a large implementation cost for a fire management system. In addition, fire suppression and burn costs balance one another: if boreal forest is allowed to burn, suppression costs go down; if it is not, suppression costs rise.[28] Carbon storage, obviously, increases with suppression; in other words, the cost of suppression is essentially the cost of sequestration.

Geopolitical and Cultural Considerations- Fires never seem to be popular, especially if people have built their homes on the land near burn sites. Ash from fires can also carry in the atmosphere and deposit in other countries; large-scale prescribed burns might require international collaboration.

Feedbacks- The issue of forest albedo is a tricky system of balances: even if there is snow cover on vegetation, reflections within the canopy scatter the radiation and do not necessarily reflect it back.[29] Fire releases GHGs and affects the albedo of a landscape in various ways. It spreads ash, but also allows snow cover and reflectivity. The feedbacks associated with forest fires are not clearly positive or negative; they are a balance between the release of GHGs and the increased albedo. Therefore, future research on taiga carbon sequestration must center on understanding the relationship between feedback cycles.

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[26] USDA Forest Service Frostfire Burn website: http://www.fs.fed.us/pnw/fera/research/targeted/frostfire/index.shtml.
[27] Canadian Forest Service Fire Research website: http://fire.cfs.nrcan.gc.ca/research/index_e.php.
[28] Emina Krcmar and G. Cornelis van Kooten, 2005. "Boreal Forest Carbon Sequestration Strategies: A Case Study of the Little Red River Cree First Nation Land Tenures": http://www.blackwell-synergy.com/doi/pdf/10.1111/j.1744-7976.2005.00022.x
[29] Betts, 2000. "Offset of the potential carbon sink from boreal forestation by decreases in surface albedo", *Nature* 408:188.

Timescale- Fire management has been a longstanding practice; it is currently being refined, and it should continue to be studied well into the future.

Short- and Long-term Benefits- The short-term benefits of fire suppression are the immediate reductions in carbon emissions; however, because of the uncertainty in the fire-albedo feedback cycles and new vs. old growth sequestration capacity, ultimately fires could prove a boon to carbon storage. Thus, the long-term benefits of fire suppression hinge on further research into the appropriate balance between old- and new-growth forest sequestration.

b) Peatlands and Permafrost

Two soil formations unique to the Arctic are permafrost and peat. Permafrost is a layer of permanently frozen soil, and peatlands are acidic accumulations of decaying organic matter on the surface of the soil horizon. Peatlands, by definition, are wetlands, and in fact worldwide compose half of the world's wetlands.[30] Both permafrost and peatlands are important to carbon mitigation because they sequester 98% of the carbon in Arctic ecosystems[31] (and worldwide, peatlands account for 30% of the world's soil carbon[32]).

When permafrost thaws, it not only forms unstable thermokarsts, or lakes, which can damage civil infrastructure, but it also emits large amounts of methane. Some of this methane is stored under the permafrost in clathrates, the frozen cages that often contain methane hydrates (discussed further below). When peatlands are disturbed, they too act as carbon emitters, and if drained widespread desertification can result. Both soils take long periods of time to form, and mitigation of disturbed soil is barely feasible. Neither soil is a carbon sink that can be manipulated to solve many GHG problems, so research should focus on the effects of warming and understanding the ecosystems associated with these soils.

R&D- Arctic soils research should emphasize an understanding of their complex nutrient cycles, of what is causing their destruction, and an examination of how to reconcile land use with soil health. Peatlands are also a potential fuel source, with fewer non-carbon GHG emissions than traditional fossil fuels, though whether they classify as fossil fuel or biomass is currently a topic of debate.[33] Study could focus, , both on peat's fuel potential, as well as on investigating the effects of warming and what might be done to

[30] Global Peatlands Initiative website: www.globalpeatlands.net.
[31] http://web.mit.edu/12.000/www/m2007/teams/finalwebsite/environment/phyenv_nutrient.html
[32] "Carbon Balance of Peatlands", USGS (2000): http://www.aswm.org/science/carbon/quebec/sym43.html
[33] International Peat Society website: www.peatsociety.org.

save the soils. Currently, major research through the Global Peatlands Initiative concentrates on world peatlands about which little is known, which should increase knowledge of peatlands in general, but unfortunately the only Arctic peatlands included in that survey are those in Siberia.[34]

Infrastructure Needs- Of concern with melting permafrost is its inability to physically support infrastructure. Even the processes of building can sometimes harm permafrost[35] and increase thermokarst formation. The U.S. Department of the Interior is currently developing a long-term permafrost monitoring network in northern Alaska, which will contribute to the Global Terrestrial Network for Permafrost and the Global Climate Observing System; initial data analysis has suggested that permafrost there has undergone significant warming in the last twenty-five years.[36] With regard to peat, if it becomes a viable contender as a fuel source, peat-specific power plants must be constructed. Finland has many, supplying much of the country's fuel demand with the peat covering 25% of its surface area. However, peat as a large-scale energy enterprise has not been developed anywhere in the world. The amount of peat in the Arctic is large, but the length of time it takes to form is long enough, perhaps, to rank peat as nonrenewable.

Implementation Costs- Implementation costs fall into two categories: infrastructure strengthening and monitoring. Both categories are relatively expensive. The cost of peat-fired power plants is not considered here because it is feasible only at a very local level or in Finland.

Geopolitical and Cultural Considerations- Of chief importance is the balance between different land-use interests and soil conservation. Development of peatlands in particular—which occurs extensively all over the world—is irreversible, yet preserving them leaves the land vulnerable to future development.[37] Soils are important to the preservation of cultures and ecosystems: peat is the traditional fuel source of many small Northern communities, so its continued use is in their interest. Peatlands also house many unique plant and animal species, and to burn a peatland is to destroy a viable ecosystem. Permafrost, as well, supports much of the Arctic ecosystem, and its degradation can disrupt traditional hunts and subsistence gathering.

[34] Global Peatlands Initiative website.
[35] USARC Report on Permafrost and Infrastructure, December 2003.
[36] *The U.S.Climate Change Science Program for FY2008*, p. 26: http://www.usgcrp.gov/usgcrp/Library/ocp2008/default.htm.
[37] International Peat Society website

Feedback Issues and Timescale- While peatlands and permafrost can only sequester seemingly small amounts of carbon at a timescale comparable to some other soils, the amount of time for which the carbon is stored is far greater.[38] Because of recent feedback, however, the carbon being released from some Northern soils is far younger than expected, indicating rapid and positive feedback.[39] The conversion of Northern soils from huge carbon sinks to huge methane sources is a frightening prospect and a likely contributor to rapid future warming.

Short- and Long-Term Benefits- The short-term benefits of protecting Arctic soils are infrastructure integrity, species diversity, and the ecological benefits accrued from wetlands (in the case of peat). Because soil carbon sequestration is a long-term process, its benefits are all long-term.

[38] Davidson et al.
[39] "Arctic Carbon a Potential Wild Card in Climate Change Scenarios": http://www.sciencedaily.com/releases/2004/04/040420213929.htm

3) Point-Source Energy Production

For many reasons, the Arctic may provide a testbed for implementation of methods of point-source energy production not based on fossil fuels. In some cases, the Arctic may be a choice due to availability of resources. In other cases, the Arctic region's generally high energy costs may encourage development and implementation of new technologies.

Much of the information in this section comes from presentations at the Arctic Energy Summit Technology Conference (AESTC) that took place in October 2007 in Anchorage, Alaska. The event featured an enormous variety of presenters, and was organized by the Institute of the North in Anchorage and co-sponsored by USARC. Such a gathering provides an unmatched opportunity for people from many different fields and nations to come together and exchange ideas, and similar events in the future should be enthusiastically encouraged.

a) Geothermal Power

An Arctic nation, Iceland, leads the world today in the use of geothermal power. Perhaps the rest of the Arctic might find geothermal energy to be the way of the future. It is domestic, virtually inexhaustible if managed correctly, and low in emissions. The technology to harness the Earth's heat is already very advanced; emissions of GHGs have actually decreased with the advent of new reinjection systems.[40] It has been proffered that enhanced geothermal systems (EGSs) might actually serve as means of storing carbon dioxide (see the "Carbon Capture and Storage" section in this report for a detailed description of carbon storage).[41] Using EGSs with supercritical carbon dioxide as a reservoir heat transfer fluid may also enhance well production and avoid the problems that water's chemistry creates.[42] Geothermal resources abound in Alaska especially,[43] with large potential in some other Arctic areas.[44] Thus, the use of geothermal as an Arctic energy resource not only has potential to supplant more carbon-intensive power production and reduce future emissions, but could also help to reduce the amount of carbon already in the atmosphere. Two challenges limit geothermal power in the Arctic regions. The first is the cost of exploration, and the second is transportation. There is large potential for hydrogen production with

[40] Presentation by Amanda Kolker, Geology PhD candidate, UAF. Anchorage Museum, 14 August 2007.
[41] "The Future of Geothermal Energy", MIT, 2006, p6.
http://www1.eere.energy.gov/geothermal/pdfs/future_geo_energy.pdf
[42] Geothermics 35 (2006) 351-367, K. Pruess. EGS with CO_2 as a working fluid.
[43] *Alaska Renewable Energy Atlas 2007*, published by the Renewable Energy Alaska Project and the Alaska Energy Authority.
[44] Digital Tectonic Activity Map of the Earth (Polar Perspective):
http://denali.gsfc.nasa.gov/dtam/downloads/ftp/dtam_poster.pdf

geothermal, as well as for transmission of geothermal energy with hydrogen when better hydrogen technologies are developed.

R&D- MIT's recently released study on the future of geothermal power outlines a number of specific R&D needs,[45] but some of the chief R&D needs for geothermal systems in the Arctic region are: remedying the remoteness between production and consumer, improved seismic sensing and monitoring to lessen start-up costs, targeted research to increase efficiency, understanding and encouraging the use of carbon dioxide as a working fluid, and improving EGS and dry cracking geothermal recovery systems.

Infrastructure Needs- While the infrastructure needed for geothermal drilling is similar to that for oil and gas drilling,[46] drilling systems could be improved. The chief infrastructure needed for an effective Arctic geothermal program, though, is a transport system to bring the power from source to consumer.[47]

Implementation Costs- Overall, because of their longevity and continuous production, with no fuel input, the operating costs of geothermal systems are far less than those of diesel energy systems. However, all of the costs of a geothermal plant are incurred at start-up because of speculative drilling and drilling production wells.[48] In addition, in areas where Enhanced Geothermal Systems (EGSs) are necessary, the already high start-up cost of a system goes up substantially.[49] The cost of a transport system for this energy will probably also be large.

Geopolitical and Cultural Considerations- Geothermal power production can offset a large percentage of domestic power production (an estimated 20% in the Alaska Railbelt alone[50]) while decreasing America's dependence on foreign fossil fuels. Geothermal also holds public appeal through its potential as a renewable home heating source (with underground heat pumps), though the cost of these systems is uncertain. Chena Hot Springs Resort in Alaska is working with the Department of Energy (DOE) to launch small-scale pilot domestic use projects, including refrigeration, heating, and running a greenhouse.[51]

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[45] See MIT study at http://www1.eere.energy.gov/geothermal/pdfs/egs_chapter_1.pdf, p. 22 for a detailed list.
[46] MIT study, p. 10.
[47] Amanda Kolker presentation
[48] Amanda Kolker presentation
[49] "Draft Strategic Plan for the DOE Geothermal Technologies Program": www.geothermal.org/DOE_presentations/JP_DOE_S.PPT
[50] Amanda Kolker presentation
[51] See Chena Hot Springs Geothermal projects website: http://www.yourownpower.com/

Feedback Issues- There are few feedback issues associated with geothermal power, so long as a reinjection system is used and the well is not overproduced. In fact, if a geothermal unit is used to capture and store carbon dioxide, it can take carbon out of the feedback cycle.

Timescale- Geothermal capability exists today, and the timescale at this point is a function of funding. The Aleutian Chain in Alaska promises a great capacity for geothermal energy, and there are currently debates about whether the community of Unalaska will convert from diesel generators. The Mt. Spurr geothermal project is in the development stages, with development applications submitted in early 2007.[52] The community of Naknek is also undertaking a large geothermal transmission project.[53]

Federal Programs- The Energy Independence and Security Act of 2007 includes funding for advanced geothermal resource detection techniques, advanced exploratory drilling techniques, EGSs, geothermal production from oil and gas fields, the establishment of a Center for Geothermal Technology Transfer, and international collaboration on geothermal technology. It also expands DOE's GeoPowering the West program into the GeoPowering America program, which covers the whole country.[54]

Short- and Long-term Benefits- The short-term benefit of geothermal power is that it can provide a low-carbon, local energy source, while in the long-term it can enhance the sustainability of the community using it, and may eventually be coupled with hydrogen transport.

b) Hydroelectric Power

Hydroelectric power is the most widespread renewable form of energy production on the planet. It supplied approximately 7% of U.S. electricity in 2006,[55] dwarfing the production from all other renewable energy sources combined, and currently supplies about 24% of Alaska's electricity.[56] It is a mature technology, and though it is widely used in Northern nations, it still has room for growth, largely because the rising prices of conventional energy sources have made various hydroelectric projects cost-competitive. In addition, studies in Scandinavia have predicted that the potential for hydro power at

[52] Amanda Kolker presentation
[53] Bailey, Alan. "Naknek Looks to Geothermal Energy" (6/17/2007): http://www.petroleumnews.com/pntruncate/881351375.shtml.
[54] From DOE's Office of Energy Efficiency and Renewable Energy (EERE) Network News (1/2/08): http://www.eere.energy.gov/news/archive.cfm/pubDate=%7Bd%20%272008%2D01%2D02%27%7D.
[55] *DOE Annual Energy Report 2007*
[56] *Alaska Renewable Energy Atlas 2007*, published by Renewable Energy Alaska Project and the Alaska Energy Authority, p. 5.

higher latitudes will only increase over the course of this century with climate change.[57] This is true both for traditional large-scale projects serving dense population centers and for small "micro-hydro" projects in more remote locations. It should be noted that energy analysts anticipate that there will be negligible new hydro power development through 2020 in the U.S. as a whole, but a relatively large project (300 megawatts) at Chakachamna Lake west of Cook Inlet is currently being evaluated by TDX Power.[58] A comprehensive DOE study from 1997 identified approximately 119 possible hydro power sites of varying sizes throughout Alaska.[59]

R&D- Hydroelectric power requires little new research or development, but there is a need for further studies on the feasibility of micro-hydro power in many rural communities. Also, micro-hydro projects in cold climates face unique challenges because of ice formation in the winter.[60] These, however, must be addressed on a case-by-case basis.

Infrastructure Needs- Besides construction of the dam itself and the associated facilities, the main infrastructure required for hydroelectric projects is transmission capacity to bring electricity from the source to users. However, this is evaluated as part of the costs of the project and does not require independent study. If hydro power is developed in combination with other renewable sources, transmission infrastructure could be shared (a possibility with the Chakachamna Lake hydro power project and the Mt. Spurr geothermal project), which could reduce costs.

Implementation Costs- Costs, of course, depend on the scale of the project. If a project is appropriate for the size of the grid it serves, it may warrant even very high initial costs, as happened with the Bradley Lake hydro power project on the Kenai Peninsula.

Geopolitical and Cultural Considerations- Because of possible impacts on the local environment and the human community, the effects of a hydro power project must be thoroughly analyzed in advance. This could be especially true for micro-hydro projects in rural locations inhabited mainly by indigenous peoples, where a project's negative impacts on the environment could outweigh its benefits. However,

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[57] Arni Snorrason presentation at AESTC, "Climate and Renewable Energy in the Nordic Countries," http://www.confmanager.com/main.cfm?cid=680&nid=8815.

[58] Bailey, Alan. "A fresh look at Chakachamna hydropower." *Petroleum News*, Sept. 9, 2007: http://www.petroleumnews.com/pntruncate/839208091.shtml.

[59] Conner, Alison M. and James E. Francfort, "U.S. Hydropower Resource Assessment for Alaska," published by Idaho National Engineering and Environmental Lab on behalf of DOE in November 1997: http://hydropower.id.doe.gov/resourceassessment/pdfs/states/ak.pdf.

[60] Brian Yanity presentation at AESTC, "Cold Climate Problems of a Micro-Hydroelectric Project on Crow Creek, Alaska," http://www.confmanager.com/main.cfm?cid=680&nid=8815

hydro power has the advantage of being the oldest and most widely accepted source of renewable energy, and it reduces dependence on foreign oil and thereby enhances energy security.

Feedback Issues- Hydroelectric projects have few associated feedback issues with regard to carbon emissions, but, depending on scale, they can have significant impacts on the surrounding environment. A dam can decrease water levels downstream, cause low oxygen levels in the water downstream, and prevent fish from reaching either the spawning grounds upstream of the dam or the ocean downstream (though methods to mitigate this problem, such as fish ladders, have been deployed in some cases).

Timescale- As with geothermal, hydro power is immediately deployable, and depends only on financing. Given the large initial investment, the careful study needed in order to prove a project viable may delay it for years.

Federal Programs- Federal support for hydro power projects appears to be at a low, because its potential for growth is small compared with other renewable sources, and because of increasing regulatory difficulties and energy economics. However, DOE still maintains some hydropower funding through the Office of Energy Efficiency and Renewable Energy's (EERE) Wind and Hydropower Technologies Program. This program focuses not on significant new technology, but rather on improvements of turbine efficiency and on reducing the environmental impact of hydro facilities.[61]

Short- and Long-term Benefits- In the short term, hydro projects can create local jobs and reduce the amount of money leaving the community to pay for fossil fuels. In the longer term, they reduce carbon emissions and, though they are vulnerable to fluctuations in water flow, they provide local and perpetual sources of reliable, clean base-load energy.

c) Wind Power

Wind power is by far the fastest-growing source of renewable energy in the U.S. Installed wind capacity grew by an impressive 45% in 2007,[62] but it still represents less than one percent of total electricity generation. It has received perhaps the greatest media attention of any of the renewables in recent years, and promises to make a substantial contribution to reducing dependence on fossil fuels. Wind power has

[61] See EERE's Wind and Hydropower Technologies website: http://www1.eere.energy.gov/windandhydro/.
[62] "U.S. Wind Capacity Up 45 Percent in 2007," from RenewableEnergyAccess.com, 1/18/2008: http://www.renewableenergyaccess.com/rea/news/story?id=51180.

great potential for expansion in Northern regions. In Alaska, those regions lie mainly—though not exclusively—on the coast, and include both the population centers of the Railbelt and many rural communities. There are several studies underway for wind projects in the Railbelt, such as the proposed site on Fire Island near Anchorage, and many remote villages have plans to incorporate wind power in the near future. The Alaska Village Electric Cooperative has already installed wind turbines in several villages, and eventually intends to install them in 27 out of the 53 communities it serves.[63] As expected, this trend is being driven by rising diesel prices and uncertain natural gas markets.

R&D- The technology of wind turbines is mature relative to many other renewables, such as photovoltaics and wave and tidal systems, and so further research should concentrate on ancillary technologies. The most important of these is storage mechanisms. Since the wind does not always blow, nor does it often blow strongly at times of peak electricity demand, excess power generated by wind turbines has the potential to overload the grid to which it is connected, or to be wasted. Thus, storage of wind power appears to be a primary factor hindering wider deployment, and no perfect solution has yet emerged. Utilities like American Electric Power are investing in large-scale chemical batteries for storage.[64] A small community in Norway is demonstrating the possibility of a system in which excess power from a wind turbine drives the production of hydrogen, so that the stored hydrogen can be used to produce electricity when the wind does not supply sufficient power.[65] (Hydrogen technology is discussed below.) Another option is Compressed Air Energy Storage (CAES), which works by using wind power in order to compress air in a special vessel, and then releasing that compressed air in order to produce electricity when it is needed.[66] Still another option is combining wind power with a hydroelectric system, so that wind power pumps water up to a higher elevation, and the water can be released on demand to drive a conventional hydro turbine, an option employed in Scandinavia.

Infrastructure Needs- Besides the need for storage, large-scale wind projects usually require new transmission infrastructure, and there are often extra costs for integrating wind power with the existing grid. This points to a general need for "smart grid" technology (discussed in greater detail below), which allows utilities to more effectively manage electricity production and demand. In addition, better systems

[63] De Marban, Alex. "Wind power gains strength as rural energy alternative." Anchorage Daily News, 1/22/2008: http://www.adn.com/front/story/290021.html.
[64] Wald, Matthew L. "Utility Will Use Batteries to Store Wind Power." New York Times, 9/11/2007: http://www.nytimes.com/2007/09/11/business/11battery.html?ref=business.
[65] David Pointing presentation at AESTC, "The NordSESIL.net Project," https://www.confmanager.com/main.cfm?cid=680&nid=8811
[66] Marcus, David. "Moving Wind to the Mainstream: Leveraging Compressed Air Energy Storage." From RenewableEnergyAccess.com, 10/1/2007: http://www.renewableenergyaccess.com/rea/news/reinsider/story?id=50123.

are needed in isolated grids, such as those in rural Alaska, for integrating wind (and other renewable) power with the diesel generators that currently supply nearly all of the electricity in those places. Wind-diesel hybrid systems come in three main forms, classified according to whether wind has low, medium or high penetration in the system; the three types are essentially separate technologies.[67] Many of the presentations at AESTC emphasized that wind power can displace a portion of diesel use in many communities, but only if it can be reliably integrated with diesel power, and only if it enjoys wide community support. Thus, technological and community decision-making infrastructure are critical to the successful deployment of wind power in remote rural settings. One other infrastructure need is greater turbine manufacturing capacity. Because of the tremendous growth nationwide in wind power, all wind turbine plants have sold out their manufacturing capacity for 2008.[68] Additionally, wind turbine production has become focused on large-scale turbines, and production of smaller turbines appropriate for rural Alaska has lagged behind. Clearly, there is a need and a possible opportunity for local production of wind turbines.

Implementation Costs- For average wind power projects connected to large grids, the majority of cost stems from initial investment in the turbines themselves and installation, with much less spent on maintenance and operations. These projects, therefore, require well-established demand and transparent regulatory processes in order to secure funding, but once installed they face relatively few risks. Projects in isolated rural communities like the villages of Alaska face the additional challenges of shipping and installing the turbines in remote and difficult environments, and then maintaining them with infrequent support through cold winters. The cost of the turbine, normally the largest expense, is often overshadowed by shipping, installation, and maintenance costs in these situations. Despite this, the rapidly rising cost of diesel has made wind power economical in many locations.

Geopolitical and Cultural Considerations- Wind power, along with the other forms of renewable energy, provides the important benefit of reducing fossil fuel use and increasing domestic energy security. Culturally, the installation of wind power in rural villages may provide a way of bringing the community together in order to develop a coordinated plan for energy use. People in many Alaskan villages eagerly seek out the opportunity to implement wind power.

[67] Edward Baring-Gould presentation at AESTC, "Status of Wind/Diesel Applications in Arctic Climates," https://www.confmanager.com/main.cfm?cid=680&nid=7255.
[68] "U.S. Wind Capacity Up 45 Percent in 2007."

Feedback Issues- Wind power has few associated feedback issues, but it does have the potential for somewhat minor environmental impacts. These include harm to birds, noise, and aesthetic alteration of the landscape.

Timescale- As noted, wind power is relatively mature as a technology and can be deployed readily given the right economic conditions, and given preliminary testing of the resources of an area.

Federal Programs- DOE's Wind and Hydropower Technologies Program supports research related to storage mechanisms (specifically, combining wind power with hydrogen or hydroelectricity) and grid integration issues. This program, however, does not address Arctic-specific needs. DOE's Wind Powering America program provides a small amount of support to wind projects in Alaska, including an anemometer loan program, consumer guides, and a wind working group. The Energy Security and Independence Act of 2007 directed DOE to establish a cost-sharing R&D program for the development of effective energy storage mechanisms; this could potentially help fund research into better storage for wind power. It should also be mentioned that the federal wind energy PTC—currently valued at 1.9 cents per kilowatt-hour for the first ten years a project operates—is currently vital to the success of a large number of wind projects nationwide. Similar PTCs are also critical for other renewables: geothermal, solar, and some bioenergy projects.[69]

Short- and Long-term Benefits- Despite the unpredictability of wind availability and the need to develop storage mechanisms and smooth integration with existing grids, wind power is an effective means of tapping a resource that abounds in many Northern regions, especially Alaska. It reduces fossil fuel dependence and increases energy security, provides local jobs, and can serve as a rallying point for communities facing energy crises. Recent experience in Alaska also suggests that planning on the regional level may be very effective in some cases for helping to develop and implement individual community wind energy plans.[70] Realistically, though, wind energy cannot provide for all or even the majority of a typical community's needs, at least in the short term. Kotzebue, which has invested the most in wind power of any rural Alaskan community and installed more than 15 turbines (which add up

[69] "Renewable Energy Tax Credit Extended Again, but Risk of Boom-Bust Cycle in Wind Industry Continues," from Union of Concerned Scientists website (1/26/2008): http://www.ucsusa.org/clean_energy/clean_energy_policies/production-tax-credit-for-renewable-energy.html

[70] Martina Dabo presentation at AESTC, "Regional Economic Wind Development in Rural Alaska": https://www.confmanager.com/communities/c680/files/hidden/Presentations/Rur-14_Regional_Wind_Power_Alaska.pdf.

to over one megawatt of capacity), receives only 5-7% of its power from wind.[71] Still, installation of wind power can reduce energy costs and begin the path toward a more sustainable local energy system.

d) Solar Power

Solar power faces special challenges in Northern regions like Alaska. Although the state receives a large amount of solar radiation in the summertime, electricity demand is greatest in the wintertime when the sun provides little energy. Because of this mismatch, most studies indicate that solar power on a large scale is not cost-effective in the Arctic. The remote town of Lime Village maintains the largest utility-connected solar capacity in the state, a photovoltaic-diesel-battery hybrid system that generates only 12 kilowatts. Various studies are continuing, however, to assess solar power's viability. For instance, solar may become cost-effective if coupled with other renewables, as is being done in a study at the Cold Climate Housing Research Center in Fairbanks, Alaska.[72] One Nome business recently installed 92 solar panels at a cost of $175,000, and expects them to offset 10-15% of its office building's electricity consumption.[73] In any case, solar power remains a good option for remote cabins or stations with small needs and limited access to other energy sources. Solar water heating systems work well during a large portion of the year, and may eventually provide in-floor heating if such technology becomes commercialized and widely available.[74] Given the ongoing large research investments from both the public and private sectors, and constant advances in solar technology, cost reductions may eventually make solar power a more attractive option in the Arctic.

e) Wave, Tidal and Osmotic Power

All three of these technologies generate electricity by the harnessing the kinetic energy of moving water, and all tap into energy sources that are more predictable and denser than wind and solar. Though wave and tidal energy have been under development for some time, recent advances have made them more feasible in many locations. However, the technology is still immature relative to some other renewable sources like wind.

[71] Brad Reeve presentation at AESTC, "Renewable Energy and Energy Planning in Northwest Alaska": http://www.confmanager.com/main.cfm?cid=680&nid=8815
[72] See the Hybrid Micro-Energy Project page at the Cold Climate Housing Research Center website: http://www.cchrc.org/research.html.
[73] "Fuel costs strap the Bush," Anchorage Daily News, 12/18/2007: http://dwb.adn.com/opinion/view/story/9526030p-9436814c.html
[74] *Alaska Renewable Energy Atlas 2007*, p. 14.

Wave energy generation systems differ in the methods used to convert kinetic wave energy into electric energy, but one good example is the AquaBuOY unit developed by Finavera Renewables, Inc. This unit uses wave energy to drive pressurized seawater through a series of hoses; the seawater then drives a turbine which produces electricity. In December 2007, Finavera became the first company in the U.S. to obtain a license from the Federal Energy Regulatory Commission (FERC) for commercial wave energy power generation, and also the first in the U.S. to sign a purchase agreement for wave power.[75] Finavera is still testing its technology, but the license and contract prove that it is a real possibility, and they could pave the way for other companies and technologies. Large-scale, feasible wave energy appears to be on its way in the U.S. Though the southern coast of Alaska possesses some of the most abundant wave resources in the world, there are currently no wave projects under development, because of the remoteness of most of the wave energy from demand centers. Some communities, however, such as Yakutat, may provide suitable sites.[76]

Tidal power systems (which, with wave power, fall under the term "ocean" or "marine" energy) also come in a wide variety of designs, though most use the water flow of the tides in order to drive a turbine. Cook Inlet in Alaska happens to possess some of the strongest tidal resources in the world, and a 2006 study concluded that a site at Cairn Point in Knik Arm could produce approximately 17 megawatts.[77] Ocean Renewable Power Company will be testing a newly-developed tidal turbine technology at Port MacKenzie and/or a more remote Alaskan site in mid-2008. The company then hopes to obtain FERC permits for commercial generation in 2010 and install its first commercial project by 2012.[78] Though this company is the first, other tidal power firms will most likely enter the Alaska market in the future due to the large resource potential, and its relative proximity to the large population center of Anchorage and the Railbelt grid. No one is certain how tidal development would be affected if the beluga whale in Cook Inlet is listed as an endangered species.

Osmotic power is even less mature than wave or tidal, but holds some promise. An osmotic power project must be located at an estuary, where freshwater meets saltwater. The plant brings in both types of water and separates them with a semi-permeable membrane. The natural process of osmosis causes the freshwater to diffuse through the membrane and increase the pressure on the saltwater side, and that pressure is then converted into electricity. The Norwegian-owned renewable energy group Statkraft plans

[75] "Wave Power Going Commercial with License and Power Contract," from EERE Network News (1/9/2008): http://www.eere.energy.gov/news/archive.cfm/pubDate=%7Bd%20%272008%2D01%2D09%27%7D
[76] *Alaska Renewable Energy Atlas 2007*, p. 12.
[77] *Alaska Renewable Energy Atlas 2007*, p. 12.
[78] Ocean Renewable Power Company presentation at AESTC, https://www.confmanager.com/communities/c680/files/hidden/Presentations/Ren-16_Alaska_Tidal_Project.pdf

to construct a prototype osmotic plant of two-to-four kilowatt size in 2008 in Norway, in order to demonstrate the technology's feasibility.[79] It claims that osmotic power will be economically competitive with other renewables within ten years.[80] At this early stage of development, the feasibility of the system is hard to estimate, and there are no specific assessments of its potential in Northern regions.

R&D- Though wave and tidal power are now approaching commercial viability, further research will undoubtedly be required to refine the designs for each as the technologies mature. Current investments in research, development and demonstration of wave and tidal power projects are hampered by the fact that very limited federal support currently exists, whether in the form of research funding or in the form of production subsidies. Though other companies have investigated it, Statkraft remains the world leader in the development of osmotic power, and will likely continue to pursue its aggressive goal of commercializing it within a decade.

Infrastructure Needs- While wave projects in the continental U.S. will most likely be developed in areas close to population centers, wave resources in Alaska are greatest in areas far from most electricity use. Thus, public investments will probably be required in order to attract private sector interest in developing this vast potential. Perhaps wave energy could be stored and transported through a hydrogen system. In any case, the development of wave power would create the need for significant supplemental infrastructure. By contrast, the world-class tidal resources of Cook Inlet are in a much better position because of their proximity to the Railbelt grid, and would require very little extra infrastructure. The same goes for osmotic power; a large number of the world's estuaries are home to cities, and so an osmotic power project could easily be sited very close to demand.

Implementation Costs- Initial costs are high for wave and tidal, but extensive studies by the Electric Power Research Institute (EPRI) suggest that with advancements in technology it will likely become competitive with other renewables within about a decade.[81] Osmotic power faces similar high initial costs, but the technology is so immature that Statkraft is not yet certain at this point that it can make the process economically feasible.[82]

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[79] "Statkraft to build world's first osmotic power plant," from Pure Energy Systems Network (3/10/2007): http://pesn.com/2007/10/07/9500451_Statkraft_osmotic_power_plant/

[80] Statkraft, "Osmotic Power: A huge renewable resource." http://www.statkraft.de/Images/Statkraft%20Osmotic%20Power_tcm4-5362.pdf

[81] Roger Bedard presentation at the Duke Global Change Center, "Overview: EPRI Ocean Energy Program" (9/14/2006): http://oceanenergy.epri.com/attachments/ocean/briefing/Duke_Sep_14.pdf.

[82] Berzon, Alexandra, "Salty Power: A Norwegian company seeks to harness power where salt water and fresh water meet" from Greentech Media (10/5/2007): http://www.greentechmedia.com/articles/salty-power-164.html.

Feedback- These forms of energy cause no carbon emissions, and very few environmental impacts. Wave energy projects have proven quite benign, with only minor concerns about conflicts with other human activities that use the sea space near shore. Tidal turbines may endanger some fish species, but not significantly. Neither causes aesthetic issues—as offshore wind projects might—because they are usually located either underwater or far enough offshore to be out of sight. Osmotic power also poses minimal environmental problems.

Timescale- Given the number of companies currently working to test and commercialize wave and tidal power, the fact that Finavera has signed a purchase agreement to supply power in northern California beginning in 2012, and the fact that Ocean Renewable Power Company plans to have a commercial unit operating by 2012, it appears that both technologies could provide significant amounts of electricity within a decade. Once commercial units are developed and scaled up, deployment could happen relatively quickly. The UK company Ocean Power Delivery, in fact, has already produced and sold the most mature wave energy device on the market, called the Pelamis.[83]

Federal Programs- The Energy Security and Independence Act of 2007 instructed DOE to create a small program for the support of ocean energy, and also to award grants to universities for the creation of National Marine Renewable Energy Research, Development and Demonstration Centers.[84] This is a modest, but important, beginning. Given the large resources in Alaska, it may be wise to devote significant funds to Northern ocean energy. Still, a PTC does not exist for any ocean energy technology, which is a major barrier to further deployment. EPRI, after its extensive studies of wave and tidal energy, recommends that the government investigate the possibility of a PTC and/or RECs for these technologies, and that it help to streamline the regulatory process for licensing and permits. The United Kingdom has been a long-time supporter of ocean energy, and may provide a good model of government support of the technology. The UK and Portugal both have plans to install marine energy projects in the next few years. The UK has established a European Marine Energy Centre, and even funded a "Wave Hub" project, a central facility connected to the mainland to which other marine energy projects can attach.[85] The U.S. government could benefit greatly from collaborating with other nations, like the UK, whose programs are more advanced. The lack of osmotic power development in the U.S. suggests that the technology may not yet merit government support.

[83] Roger Bedard presentation
[84] From DOE's Office of Energy Efficiency and Renewable Energy (EERE) Network News (1/9/2008): http://www.eere.energy.gov/news/archive.cfm/pubDate=%7Bd%20%272008%2D01%2D02%27%7D.
[85] Roger Bedard presentation

Short- and Long-term Benefits- Like other renewables, these technologies promise clean energy from abundant and inexhaustible sources, and also the creation of local jobs and the reduction of fossil fuel use. Besides that, these methods have the added benefit of being more predictable, denser in energy, and less intermittent than sources like solar and wind. Beyond the short-term, it is possible that tidal technology could be adapted to "run of river" applications, and also that both wave and tidal projects could be combined with offshore wind projects in order to reduce costs.[86]

f) Biomass Power

"Biomass" is a very general term that includes a wide range of organic materials that can be converted into energy, everything from food crops like corn and soybeans to particular types of algae capable of producing biodiesel fuel. However, biomass resources in the Arctic are not quite so varied. In Alaska, the main biomass resources are wood, sawmill wastes, fish byproducts and municipal waste.[87]

Alaska uses approximately 100,000 cords of wood per year for heating purposes, and so wood constitutes an important renewable resource for the state. After the closure in the 1990s of the pulp mills in Sitka and Ketchikan, large-scale wood-fired power generation came to an end, but rising fuel prices have again generated interest in using wood and wood waste for power generation and possibly for ethanol production.[88] For example, a wood-powered district heating system for Craig, Alaska is currently in design.[89] Villages in the Bethel area are currently considering commercial firewood harvests around the Kuskokwim River.[90] Nordic countries as a whole generate 14% of their energy from biomass, and Sweden generates about 48% of its district heating energy from biomass, with the other Nordic nations falling between fifteen and eight percent.[91] If district heating becomes more widespread in Alaska, biomass may provide an excellent energy source. In addition, wood energy in the wintertime could be combined with solar energy in the summertime in order to provide a year-round hybrid renewable energy source. The Cold Climate Housing Research Center in Fairbanks is currently testing such a system.[92]

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[86] Roger Bedard presentation
[87] *Alaska Renewable Energy Atlas 2007*, p. 6.
[88] *Alaska Renewable Energy Atlas 2007*, p. 6.
[89] Alaska Energy Authority website: http://www.aidea.org/AEA/programsalternativebiomass.html.
[90] Bluemink, Elizabeth. "Nome group taps sun for power." Anchorage Daily News (12/2/2007): http://dwb.adn.com/news/alaska/rural/story/9493939p-9404794c.html.
[91] Jorgenson, Birte Holst, "Bioenergy—The Future of Renewable Energy?" from Nordic Energy Research (12/20/2007): http://www.nordicenergy.net/onenews.cfm?Id=3-99&path=8.
[92] Associated Press. "Researchers test energy potential of winter sun," from Anchorage Daily News (12/23/2007): http://www.adn.com/news/environment/story/245096.html.

Fish byproducts have great potential in Alaska as an energy resource, since fish processing operations in the state annually produce approximately thirteen million gallons of fish oil waste. This oil can either be mixed with conventional diesel in a traditional boiler system or manufactured into biodiesel. UniSea, Inc., a fish processing company in Dutch Harbor, currently uses up to one million gallons per year of a 70% fish oil-diesel mixture in order to power its operations. Some groups in larger Alaskan cities reuse cooking oil for heating and transportation fuel.[93] Thus, biomass in the form of oils offers a significant resource for both commercial and personal use that would otherwise be entirely wasted. Locally-made biodiesel offers a particularly attractive opportunity for rural communities, which depend almost entirely on diesel, to obtain their fuel from renewable sources and to reduce their carbon emissions.

Municipal waste, in the larger cities of Anchorage and Fairbanks especially, offers another potential energy source that would otherwise go unused. A 2005 study concluded that methane gas from the landfill in Anchorage could provide a feasible source of the equivalent of 2.5 megawatts of electricity or 1.9 millions gallons of diesel per year for the next ten years. Eielson Air Force Base near Fairbanks uses densified paper waste from the city in its coal plant, which provides up to 1.5% of the base's heat and power.[94]

R&D- R&D needs for the biomass options available in Alaska are generally limited. Wood-fired technology requires little. Many studies have demonstrated the viability of fish oils as fuel. Extraction and conversion of landfill gas is a proven technology already operating in hundreds of locations, though its feasibility depends on the presence of a large enough gas source. Paper waste is easily burned in a coal-fired power plant. In each case, future improvements in efficiency and design will bring down costs and enhance the ability of each to compete with conventional energy sources.

Infrastructure Needs- Again, these vary greatly. On the whole, biomass power is more flexible with regard to location, since the resource is usually portable, than wind, geothermal, etc. Thus, biomass tends to require much less ancillary infrastructure development than more remote renewable energy sources. Despite fish oil biodiesel's great potential in Alaska, economic feasibility studies—conducted jointly by the Alaska Energy Authority, the Alaska Department of Environmental Conservation, the University of Alaska Fairbanks' (UAF) Arctic Energy Technology Development Laboratory (AETDL), and the

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[93] *Alaska Renewable Energy Atlas 2007*, p. 6. For information about local groups, see www.alaskabiodiesel.com and www.alaskabiodiesel.org.

[94] *Alaska Renewable Energy Atlas 2007*, p. 6.

National Park Service—are still in progress to determine whether local large-scale biodiesel production facilities in the state would be cost-effective.[95] Such facilities would greatly enhance advance the use of biodiesel in Alaska.

Implementation Costs- Costs appear to be relatively low for sources like fish oil, where the main cost is the facilities for capturing the oil and mixing it with diesel or manufacturing biodiesel; however, the equipment for converting it into biodiesel would have high initial costs. The great advantage of biodiesel is that it can be used in normal diesel engines, whereas raw fish oil can only be used as a part of a mixture. Landfill gas extraction also requires a high initial investment. Thus, costs vary by the biomass source, but on the whole they have usually been found to be worth the investment. The use of biomass in combined heat and power systems (discussed below) has the potential to maximize energy output per unit of fuel and therefore make biomass even more feasible; in fact, the majority of current biomass energy comes from combined heat and power systems.

Feedback- If living trees in the Arctic were to be harvested specifically as a form of biomass energy, this would clearly affect the carbon sink of the boreal forests, but biomass usually refers to waste material that would otherwise go unused, at least by humans. Thus, appropriate use of wood biomass would not significantly increase carbon emissions or affect carbon sinks. Fish oil mixed with ordinary diesel, or converted into biodiesel, produces substantially fewer carbon emissions than diesel alone. The use of both paper waste and landfill gas reduces carbon emissions: garbage, as it decomposes in a landfill, naturally releases considerable amounts of carbon dioxide, methane and other trace compounds, and landfill gas extraction prevents a portion of this carbon from entering the atmosphere, while converting it into useful energy. The burning of paper waste reduces carbon emissions first by reducing the volume of waste in the landfill, and second by offsetting some of the coal used in a coal plant.

Timescale- All of the biomass energy sources discussed here are currently in use, and could be developed quickly if funded.

Federal Programs- Current federal investments in biomass energy focus mainly on the production of biofuels for automobiles. The large-scale production of biodiesel from fish oils may eventually help to meet the federal Renewable Fuel Standard, which mandates that the U.S. produce 7.5 billion gallons of biofuel annually by 2012, and even more in the following years. This focus on biofuels, while it may be good for fish oils, means that federal agencies have directed little funding toward wood biomass, except

[95] Alaska Energy Authority website: http://www.aidea.org/AEA/programsalternativebiomass.html.

as a source of cellulosic ethanol. Landfill gas projects, however, receive a PTC under federal law of one cent per kilowatt-hour for the first ten years of operation, and so enjoy a considerable subsidy.

Short- and Long-term Benefits- In addition to providing renewable energy in the short term, biomass reduces the human waste stream by harnessing energy stored in that waste. The sustainability of society depends in large part on its ability to use energy efficiently and recycle materials, and so in the long term, biomass energy contributes to sustainability.

g) Hydrogen and Fuel Cell Technology

Hydrogen, as a carrier of electricity, holds great potential for the future, especially when coupled with renewable energy-generation technologies. Elemental hydrogen can be produced in many ways, e.g. from hydrocarbon sources or from water by electrolysis; in either case, energy must be expended in order to separate hydrogen from the hydrocarbon or water. The hydrogen so produced must be stored in a vessel of some kind, transported, and then consumed at the end-use point. Because of inefficiencies in current methods, hydrogen production and transport are energy sinks and will probably remain so, but research into these areas will greatly benefit future energy transport, since the technology offers a carbon-free energy carrier mechanism that takes advantage of the most abundant element in the universe.

At the moment, Iceland is the nation most aggressively developing hydrogen energy infrastructure—its stated goal is the use of hydrogen to power all transportation in the country by 2050.[96] Because it obtains almost all of its other energy from hydroelectric and geothermal facilities, it could become the first country to power itself completely with carbon-free energy sources. The U.S. maintains a partnership with Iceland that focuses on rapid development of hydrogen, and both are part of the International Partnership for the Hydrogen Economy (IPHE), an organization of 15 developed nations and the European Commission that promotes the advancement and deployment of hydrogen technology and fuel cells.[97]

While "hydrogen technology" refers to the use of hydrogen as a fuel source, the term "fuel cell" refers to a particular type of mechanism that directly converts chemical to electrical energy. The two are separate technologies, but they go hand in hand. A fuel cell is divided into two compartments, separated by a

[96] Icelandic New Energy Ltd. presentation at AESTC, "Hydrogen Economy Meeting Future Energy Needs: Arctic Vision," https://www.confmanager.com/communities/c680/files/hidden/Presentations/Ren-09_Hydrogen_Economy.pdf.
[97] IPHE website: http://www.iphe.net/

special membrane, called the electrolyte. In the typical fuel cell, hydrogen enters the first compartment, where a catalyst (often platinum or a similar metal) causes the hydrogen to dissociate into protons and electrons; the membrane allows only the protons to diffuse through to the other compartment, while directing the electrons through an external circuit, where this electron flow generates electricity. The electrons and protons combine with oxygen in the other compartment in order to form water, and release a large amount of heat in the process. Of course, variations of this basic fuel cell type exist, which use hydrocarbons such as methanol rather than pure hydrogen as fuel.

Dennis Witmer, of the AETDL at UAF, identifies five main types of electrolytes used in fuel cells: alkaline, phosphoric acid, molten carbonate, solid oxide, and polymer exchange membrane (PEM). Witmer believes that alkaline is not viable on any large scale, that phosphoric acid is commercialized but still too expensive, that molten carbonate is still in the pre-commercial development stage, that solid oxide is promising but still too expensive, and that PEM units still degrade too quickly. His main conclusion is that hydrogen and fuel cell infrastructure will not become viable until consumers are willing and able to pay more for energy than they currently do.[98]

R&D- Despite decades of research and development, hydrogen and fuel cell technology still faces significant challenges before it can become a widespread replacement for the current fossil fuel infrastructure. First, there are concerns about the efficiency of hydrogen production. As noted, hydrogen would function more like electricity than gasoline, i.e. as an energy carrier rather than an energy source. Approaches to hydrogen production still differ greatly. And, as Witmer observes, further research into electrolytes and other technical components of the fuel cell is needed in order to improve efficiency and durability. Almost every aspect of the storage, distribution and transportation of hydrogen remains a concern—including the cost of storing high-pressure hydrogen gas or liquefied hydrogen, the safety of storing hydrogen (given its instability in elemental form), and the distribution mechanisms for hydrogen (whether it would be produced at central plants or at decentralized locations resembling today's gas stations). Research in all of these areas will likely continue for decades to come.

Infrastructure Needs- The development of a "hydrogen economy" is a long-term goal and is by no means a certainty at this point, because much research is still required, and also because it will necessitate a massive investment in infrastructure over a considerable period of time. Cost-effective, safe and reliable technology for the production, storage, and transportation of hydrogen and for fuel cells may not

[98] Dennis Witmer presentation at AESTC, "Hydrogen and Fuel Cell Demonstrations in Alaska," http://www.confmanager.com/main.cfm?cid=680&nid=8813.

be available for well over a decade, and will probably not achieve substantial market penetration until years after that. Essentially, an entirely new energy infrastructure would be necessary in order for hydrogen technology to displace fossil fuels. There are some ideas, however, for employing existing infrastructure; one of these is the use of natural gas pipelines for the transport of hydrogen.

Implementation Costs- The costs of implementing hydrogen technology will be high not only because of the large infrastructure investment needed, but because the price of hydrogen production and of fuel cells is likely to remain high for the foreseeable future.

Feedback- The typical fuel cell which uses pure hydrogen emits no carbon, while fuel cells using various hydrocarbon sources do produce carbon emissions, although in small amounts compared to internal combustion engines. If the energy for the production of hydrogen comes from fossil fuel sources, the entire hydrogen infrastructure may cause substantial emissions; therefore, it is important that hydrogen technology be coupled with renewable energy sources.

Timescale- The timescale for deployment is still uncertain at this point, because of the uncertainty about the rate at which hydrogen and fuel cell technology will be commercialized. Most likely hydrogen will not have a substantial impact in the U.S. or in the Arctic (except Iceland) for at least a decade.

Federal Programs- The CCTP's near-term goal for hydrogen and fuel cell development is to research and develop all the technologies supporting the envisioned "hydrogen economy" at a pace such that a decision can be made by 2015 about the long-term viability of hydrogen and fuel cell infrastructure for energy storage, transportation needs, electricity generation, etc.[99] Federal programs like DOE's Hydrogen, Fuel Cells and Infrastructure Technologies Program tend to focus on the development of hydrogen technology for the auto market, and only secondarily on stationary fuel cells and energy storage. In any case, the infusion of billions of dollars of federal money into the industry, which currently struggles largely because of a miniscule market, will undoubtedly enable it to advance far more quickly than would otherwise be possible. There are no federal programs that specifically address the development of hydrogen and fuel cell technology for the Arctic, though the Norwegian wind-hydrogen system mentioned above indicates that there may be an opportunity for a similar demonstration project in Alaska.

[99] *U.S. Climate Change Technology Program Strategic Plan*, September 2006, p. 90.

Short- and Long-term Benefits- Though hydrogen is often touted as the future of energy and a solution to dependence on imported fossil fuels, it should be remembered that hydrogen is an energy carrier, and that it can only reduce carbon emissions if it is produced using renewable energy sources or sources that incorporate carbon sequestration. Thus, the development of hydrogen and fuel cell technology should only be pursued in the context of a long-term policy to reduce carbon emissions from all primary energy sources. One of hydrogen's greatest benefits, in fact, may stem from its use as a store for the energy produced by intermittent renewable sources like solar and wind, and not from its use as an automotive fuel. This may be particularly true for rural Arctic communities with abundant renewable energy resources, where hydrogen could be used to store the energy for local use and also for export.

h) Nuclear Power

Though nuclear power is regarded as a conventional power source, the fact that it contributes little or no carbon to the atmosphere means that it can be an important part of a carbon mitigation portfolio. It has been a major commercial supplier of power for decades, and is therefore well-established, though it has often faced fierce citizen opposition, especially after the incidents at Three Mile Island and Chernobyl, and fears about nuclear proliferation. In the face of climate change impacts, rising energy costs, and increasing security concerns, nuclear power appears to be making a comeback in the U.S.[100] and some European countries, and constitutes an integral part of the energy strategy of developing nations like China. Among Arctic nations, Sweden overshadows all others, deriving about 46% of its electricity from nuclear, while Finland uses nuclear for 28% of its electricity.[101] Currently, only one nuclear project has been proposed in Alaska, in the small community of Galena. It would be the first non-military reactor in the state. Though the project is moving forward, and has the potential to provide low-cost energy for Galena, it faces strong skepticism and could end up costing much more than planned by the time it is installed in 2012.[102] But if the reactor is built and lives up to promises, it could generate enough excess power to produce hydrogen for fuel cells, and also enough heat for a district heating system.

R&D- Though nuclear technology is quite mature, ongoing research continually seeks to develop new better reactor types and improve the efficiency of existing plants. One example is the new, small and relatively simple design of the Galena reactor, proposed by the Toshiba Corporation of Japan. Many

[100] "Companies File the First Nuclear Plant Application in 29 Years," from EERE Network News (9/26/2007): http://www.eere.energy.gov/news/archive.cfm/pubDate=%7Bd%20%272008%2D01%2D09%27%7D.
[101] Arni Snorrason presentation at AESTC, "Climate and Renewable Energy in the Nordic Countries," http://www.confmanager.com/main.cfm?cid=680&nid=8815.
[102] Gay, Joel, "Village invited to test cheap, clean nuclear power," from Anchorage Daily News (10/21/2003): http://dwb.adn.com/front/story/4214182p-4226215c.html.

agree that the new design should work well in theory, but it has never been tested, and U.S. regulators require the construction of a prototype before the actual plant is built. The performance of the prototype should indicate the viability of this new reactor type.

Infrastructure Needs- The main supplementary infrastructure associated with nuclear power is a method for disposal of the nuclear waste generated. This need remains a significant problem for future development of nuclear power, since the proposed federal disposal site at Yucca Mountain has yet to be approved. Nuclear reactors are usually sited near demand, so they do not require significant investments in transmission lines.

Implementation Costs- Initial costs are high for nuclear power projects, because of the size and complexity of the projects and because of the price of insurance required to cover the costs of a possible accident. The final cost of the Galena reactor is still uncertain because the design is unproven, but it is likely to be less than a standard plant, due to its small size and relatively low potential for an accident.

Feedback- Nuclear power emits no carbon, but it does pose the significant environmental problem of nuclear waste disposal.

Timescale- Regulatory hurdles and the size of nuclear projects generally cause about a ten year delay between the proposal of a nuclear plant and its completion. Since the technology is well-established, funding, regulation and popular opposition are the main factors affecting the deployment of nuclear power.

Federal Programs- President Bush's National Energy Policy[103] declares that the nation's growing need for base-load electricity generation can and should be partially met by the development of new nuclear plants, and it now appears that new nuclear capacity will be coming online in the next decade. No federal plans exist for the development of nuclear energy in the Arctic.

Short- and Long-term Benefits- Though the waste disposal problem remains a significant issue, a small and relatively safe reactor like the one proposed for Galena could prove to be an important model, if it is successful. For some rural Arctic communities, such reactors could reduce energy costs substantially. In the longer term, however, more sustainable and less risky energy sources should be preferred.

[103] *National Energy Policy: Report of the National Energy Policy Development Group*, May 2001.

4) Energy Conservation and Efficiency Measures

Above-average energy prices, especially in the rural Arctic, provide strong incentives for the adoption various practices and technologies that can reduce overall energy use, and also reduce the intensity of energy use. Thus, the measures discussed here may be feasible and desirable in the Arctic earlier than elsewhere. This does not constitute an exhaustive list by any means, only a selection of particularly appropriate strategies for the Arctic.

a) Personal Conservation and Efficiency, and Community Planning

As is often said, voluntary energy conservation and efficiency by individual citizens and businesses constitutes the cheapest and quickest way to reduce energy use and carbon emissions. Of course, such conservation, in order to have a significant impact, must take place on a large scale. This requires education about environmental issues and energy use. Though conservation cannot mitigate climate change on its own, and the development of other mitigation strategies like carbon sequestration are important, carbon mitigation should begin with education in order to be most effective. This awareness must then inform not only personal actions like deciding to turn down the thermostat or buy an energy-efficient appliance, but also extend to the community level, informing local planning processes and prioritizing issues of sustainability. The recently published Fairbanks energy plan[104] provides a good example in the Arctic of how an awareness of sustainability issues can lead to a holistic planning approach and a broad community commitment to pursuing the best—and not necessarily the cheapest—option when it comes to energy production and consumption. A sharing of "best practices" among Arctic nations may be a worthwhile endeavor.

At the individual level, energy conservation can take many forms: personal actions such as carpooling; walking or biking instead of driving when possible; turning down the thermostat and using less hot water; cutting back on personal electronics and unplugging appliances when not in use; and also consumer choices, such as buying energy-efficient appliances and lighting; buying less fuel-intensive cars; installing solar panels or other small-scale renewable energy sources; and buying locally harvested food and locally made products. At the community level, actions may include land use planning laws that discourage "urban sprawl" development patterns and make the area more pedestrian- and cyclist-friendly; more

[104] "Fairbanks Energy: Strategic Business Plan," published by the Fairbanks Economic Development Corporation in November 2007: http://investfairbanks.com/documents/FairbanksEnergy2.pdf.

stringent building codes to encourage the construction of more energy-efficient houses and offices[105] and the adoption of general energy efficiency standards; expanded public transit options; and a school curriculum that incorporates energy and environmental issues at all levels. The enormous challenge of climate change can be addressed not only by top-down policy and technological development, but also from the bottom up by some (usually modest) sacrifices on the part of individuals and communities.

R&D- Community leaders need to perform research about the current level of awareness and receptiveness to energy conservation measures among their constituents before making any sort of broad future plans. Residents of the Arctic are probably more aware of energy issues than average because costs are usually so far above average, and this presents the opportunity to highlight the large potential cost savings to individuals and cities that energy conservation can provide. This research may then lead to the development of effective methods for educating citizens about energy use and related environmental issues.

Infrastructure Needs- Infrastructure to encourage energy conservation should begin with the establishment of a dedicated group of community members who will focus on the issue. Information should be gathered into one central location where citizens can access it, but should also be disseminated in whatever way is deemed most effective—whether by town meetings, media outlets like pamphlets and newspapers and television, or through the schools. School curriculums should include energy education.

Implementation Costs- These vary greatly depending on the measures taken. Individual choices cost nothing. Consumer choices like efficient appliances can be expensive, but often return the investment within a short period of time. Community planning choices like land use reform only incur costs in the sense of requiring planners to discard old habits. Changes in building codes and school curriculum do entail real costs, but these will almost certainly be balanced by the energy savings they bring, especially in the longer term.

Timescale- Many of the actions discussed here can be implemented immediately. Changes in community planning practices and education campaigns take longer to have an impact, but can always begin without much delay if the community demonstrates the political will to do so.

[105] The U.S. Green Building Council's LEED standards provide the recognized benchmark for evaluating the efficiency and environmental impact of building practices. The USGBC is now running a pilot program for a rating system on a larger scale, the LEED for Neighborhood Development, and is expected to release the post-pilot rating system in 2009. See the USGBC website: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148.

Federal Programs- Though the federal government does little to promote personal conservation measures, it does maintain programs like Energy STAR that help consumers to select energy-efficient appliances. The government usually allows individual states and communities to set their own policies with regard to conservation and planning.

Short- and Long-term Benefits- Personal conservation and efficiency measures, when combined with larger community action, have the potential for significant cost savings in the short term, beginning almost immediately, and can also bring lasting long-term benefits. Present investments in education of citizens and in community planning practices may not only lead to cost savings in the future, but may make the area attractive to new residents. Many of the fastest-growing and most attractive cities in the U.S. have invested in public transit and made commitments to sound planning, responsible energy use and environmental protection. And initiatives at the state and national level can always aid local communities in developing and implementing energy plans and better planning practices.

b) "Smart Grid" Technologies

The term "smart grid" refers to a wide range of technologies that allow for an exchange of information between utilities and customers about electricity rates and usage, and also enable the utility to more actively manage load on the grid by reducing demand at peak load times and decreasing supply at off-peak times. They create significant cost savings for both customers and suppliers, increase the efficiency and security of the grid, reduce the frequency and length of blackouts and other disturbances, and delay the need for additions in both generating and transmission capacities.

A recent test program in the state of Washington demonstrated that when 112 households were given real-time information about electricity and heating use, and were allowed to pre-set their preferences, they achieved average cost (and energy) savings of 10% over the course of a year, and some significantly more. Such savings can reduce utility peak loads by up to 15%.[106] A Danish company has introduced a product called the "Electronic Housekeeper," and claims that it can reduce household energy bills by up to half; it is, however, still quite expensive.[107] Though such systems are not likely to become common in every household very soon, they show that consumers will conserve if given better information about energy use and prices. Such technology could be very effective in both urban and rural areas of the

[106] Lohr, Steve, "Digital Tools Help Customers Save Energy, Study Finds," from New York Times (1/10/2008): http://www.nytimes.com/2008/01/10/technology/10energy.html?ref=business.
[107] "Using a computerised monitor can help reduce electricity usage in the home during the hours when energy is at its most expensive," from Copenhagen Post (8/10/2007): http://www.cphpost.dk/get/103798.html.

Arctic, given high energy prices. A program of prepay metering systems in 21 small rural villages in Alaska has shown that customers will conserve when given sufficient information. A survey of customers using such a system on St. George Island in the Bering Sea found that 100% were conserving energy as a result, 100% were satisfied with the service, and that demand at the local power plant decreased.[108] Thus, while many of the more sophisticated supply-side "smart grid" technologies may not be cost-effective in the relatively small market of Alaska, some demand-side technologies may be well worth the investment.

R&D- Most of the smart grid tools applicable to Alaska and other Arctic regions appear to be well-developed at this point. But extensive development is still needed for utility management systems that incorporate energy storage mechanisms and integrate "distributed generation"—local renewable sources, local combined heat and power sources, etc.—into existing grids.

Infrastructure Needs- The wide application of smart grid technology requires a substantial deployment of technologies like prepay meter systems, and also the training of personnel to both install and monitor the systems. These systems are usually designed to be integrated with existing power generation configurations, so additional upgrades to generation equipment are not necessary.

Implementation Costs- Initial costs can be high for these smart grid technologies—the prepay meter systems installed in St. George cost $1,109 per household (which is actually less than the average annual household utility bill on the island), in addition to a community-wide start-up cost of about $12,000.[109] However, in many cases they can create substantial cost savings, and also increase the reliability of payment by customers in rural areas.

Timescale- Because most of the technologies exist today, funding is the main limiting factor for the implementation of smart grid systems.

Federal Programs- DOE's Office of Electricity Delivery and Energy Reliability coordinates many of the federal research and development activities surrounding smart grid technology. The goals set out in the

[108] Mike Brubaker presentation at AESTC, "Prepay Utility Meter Systems: A Case Study from the Aleut Region": https://www.confmanager.com/communities/c680/files/hidden/Presentations/Rur-10_Utility_Meters_Rural_AK.pdf.
[109] Mike Brubaker presentation

Office's 2007 Strategic Plan[110] will likely have limited impact in the Arctic. The CCTP outlines the research goal of testing a full prototype smart grid system somewhere in the U.S. by 2010.[111] Some Arctic communities, however, may be able to apply for federal infrastructure grants in order to fund smart grid technology implementation.

Short- and Long-term Benefits- Cost savings and improvements in electricity service are the primary quantifiable short-term benefits of smart grid technology. Over time, by allowing utilities to manage load so as to increase efficiency, the energy savings can reduce the need for new infrastructure like power plants and transmission lines, and thus contribute even more significantly to curbing carbon emissions. Perhaps just as importantly, though, smart grid systems promote awareness of energy use and encourage energy conservation by consumers, which can have long-term benefits that exceed mere cost savings.

c) Combined Heat and Power Systems

Combined heat and power (CHP) systems use a single energy source in order to produce both electric power and heat. They are usually envisioned as a localized energy source for a single building or small community with district heating, and come in a variety of designs that utilize a wide range of possible fuels: natural gas, solid biomass material, biogas (e.g. landfill gas), coal, oil and waste heat. Essentially, they are not a single technology but rather a general form of integrated energy system that can be adapted to the needs of the user. Their main benefit is an increase in energy efficiency. First, since they produce energy locally, they eliminate the need for transmission capacity and thus save the energy dissipated over long-distance electric lines. Second, they produce more energy per unit of fuel input than traditional systems, because they take advantage of excess heat. The average power plant in the U.S. converts only about a third of its fuel into usable electricity and expels the rest as heat, while a CHP system can convert 70% or more of the fuel into usable electricity and heat.[112] CHP can largely insulate a facility from the danger of large-scale grid blackouts, and any excess electricity not used locally can be sold back to the grid. Two main types of CHP exist—the gas turbine or reciprocating engine with a heat recovery unit, and the steam boiler with a steam turbine.

[110] *Transforming Electricity Delivery*, the Strategic Plan for the Research and Development Division of the Office of Electricity Delivery and Energy Reliability, September 2007: http://www.oe.energy.gov/DocumentsandMedia/RD_Strategic_Plan_Final07.pdf.
[111] *U.S. Climate Change Technology Program Strategic Plan 2006*, p. 76.
[112] *U.S. Climate Change Technology Program Strategic Plan 2006*, p. 76.

The second type operates by using solid biomass material or coal to run a boiler, which heats water into steam. This steam powers a turbine that produces electricity, and can then be used for heating or cooling instead of being lost. This type is more suited for industrial facilities that can keep a stock of solid fuel for the boiler.[114]

In the rural Arctic, the idea of cogeneration of power and heat may find another form: the use of a heat recovery system connected to a diesel generator. Diesel generators waste roughly 30% of the energy in diesel fuel as excess heat, and so, especially given the high energy prices and reliance on diesel for power in most rural Alaskan communities, this technology could significantly increase energy efficiency and reduce diesel demand. Moreover, it is flexible, in that it could be coupled with a variety of heating needs, including space and community water loop heating, desalination, thermal electric conversion, heat to power conversion, and heat for refrigeration and air conditioning. A group of engineers at UAF recently designed and tested such a system in the laboratory and found that it worked well—the system performed reliably over one year, did not affect the operation of the diesel generator itself, had no corrosion problems, and had low levels of soot deposits. The team estimated that the heat recovery system would pay for itself in cost savings within three to four years, though this would depend on particular circumstances. They also proposed that such a heat recovery system may become more cost-effective as ultra-low sulfur diesel (which is less corrosive than normal diesel and better suited to heat recovery) becomes standard by 2011. Though they cautioned that further testing is needed and each community should evaluate the use of heat recovery individually, such a system shows promise for increasing the efficiency of diesel use, which could have a major impact on energy costs in the Arctic over time.[115]

R&D- In order to maximize the efficiency of CHP mechanisms further technological development is needed, although high-performing systems are currently in use. These needs vary depending on the type of CHP system under consideration, but at present most consist of incremental improvements in efficiency and not basic advances in science or technology. Further testing and actual demonstration projects are necessary for diesel generator heat recovery systems.

Infrastructure Needs- A CHP system requires a fuel source and a building to which it will provide energy. If a CHP system is to be installed in an existing facility, the optimal type of system will largely

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[114] U.S. EPA CHP Partnership website

[115] UAF presentation at AESTC, "The Selection and Design of an Exhaust Heat Recovery Application for Diesel Generators Used in Alaskan Villages": https://www.confmanager.com/communities/c680/files/hidden/Presentations/Rur-06_Heat_Recovery_Diesel_Generators.pdf.

depend on the type of fuel available and the cost of integrating the system into the facility. In this case, the pre-existing infrastructure will, for the most part, determine how a CHP system is implemented, and little extra infrastructure will be required. If a CHP system is incorporated into the design of a new building, this will reduce the cost of integrating CHP and also allow flexibility in choosing the types of system and fuel used; in other words, the infrastructure of the building can be designed around or in combination with a CHP system. CHP systems can provide great efficiency gains, but their full benefit cannot be realized without the larger-scale implementation of the "smart grid" systems discussed above, which will allow excess power from CHP to be sold back to the grid. Thus, especially in the longer term, "smart grid" technology is one of the most important infrastructure needs for CHP systems.

Implementation Costs- Initial costs can be high, but even very high costs can be repaid if the CHP system installed is particularly efficient within its specific context. The U.S. EPA CHP Partnership estimates that CHP may be a good option for buildings that pay more than $0.07 per kilowatt-hour, given a capital cost of $1,200 per kilowatt capacity installed.[116] Initial installation costs may be significantly higher in Arctic locations, but the corresponding higher price of energy may mean that CHP is a cost-effective option for many Arctic buildings and communities. Feasibility for CHP always varies greatly depending on circumstances. In the case of biomass- or biogas-fueled CHP systems, various funding opportunities and tax incentives may be accessible that can make a marginal project economical. The Cold Climate Housing Research Center (CCHRC) in Fairbanks, Alaska is currently testing a biomass-fired CHP system as a supplement to solar power in its Hybrid-Micro Energy Project.[117]

Feedback- CHP systems do emit carbon, although the amount varies based on the fuel used in the system. Natural gas emits less than oil, which emits less than coal. Biomass may emit even less than natural gas. Still, they are a great improvement over conventional fossil fuel power plants because they generate much more usable energy per unit of fuel.

Timescale- The technology exists today and is used in a wide variety of situations. Funding, along with interest in the technology, remain the limiting factors to its further deployment.

Federal Programs- CHP technology is coordinated largely through the Environmental Protection Agency's (EPA) CHP Partnership, a voluntary program that brings together the CHP industry, state and local governments, and possible CHP users, and is aimed at coordinating CHP development projects and

[116] See the U.S. EPA CHP Partnership website: http://www.epa.gov/chp/.
[117] See the CCHRC website: http://www.cchrc.org/research.html.

promoting the environmental and energy-efficiency benefits of CHP technology.[118] The CCTP highlights CHP as one of the forms of "distributed generation" that will help to modernize and strengthen the nation's electricity infrastructure, and aims to make a wide array of CHP technologies cost-effective and to promote their widespread adoption by 2015.[119] A study by DOE's Federal Energy Management Program (FEMP) found that a significant number of federal facilities in the state of Alaska could achieve energy cost savings if they installed CHP systems,[120] indicating that a large number of non-federal facilities might benefit from CHP as well. Beyond energy savings, biomass and biogas projects qualify for a federal PTC that greatly enhances their feasibility in many cases.

Short- and Long-term Benefits- CHP promises significant short- and long-term benefits, primarily in the form of greater energy efficiency, which brings both short-term cost savings and long-term reductions in carbon emissions. In the longer term, CHP can lead the move toward distributed generation, and, when integrated with "smart grid" technologies, eventually enhance the flexibility and resilience of the whole energy infrastructure. Moreover, the large-scale use of biomass and biogas as fuel will reduce emissions and dependence on fossil fuels while taking advantage of an energy source that would usually go to waste otherwise.

d) Building Design and Practices

A number of Arctic building experts, recently convened at the Sustainable Northern Shelter Forum in Fairbanks by CCHRC,[121] all agreed that a focus on the building "envelope" (the parts of the building that interface with the outside) is the most cost-effective way of reducing the energy usage of houses and commercial buildings, since a better envelope can not only reduce the amount of energy needed to maintain temperature, but also maintain temperature so well that smaller and simpler heating equipment can be used. The envelope includes the insulation in walls and floors and ceilings, the windows, and the entryways. The experts also agreed that there is a great need to design buildings (and, by extension, communities) holistically, rather than piece-by-piece, in order to achieve the greatest energy savings and simultaneously create livable spaces. The CCHRC Forum showed that a sharing of "best building practices" among Arctic nations is highly valuable and should be pursued further in the future.

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[118] U.S. EPA CHP Partnership website: http://www.epa.gov/chp/.
[119] *U.S. Climate Change Technology Program Strategic Plan 2006*, p. 76.
[120] FEMP Report "CHP Potential at Federal Sites": http://www1.eere.energy.gov/femp/pdfs/chp_execsumm_5-16.pdf.
[121] CCHRC website: http://www.cchrc.org/forum.html.

Holistic building design would include: siting and orienting a structure (preferably within the context of a well-planned community) so as to maximize passive solar gain via south-facing windows, minimize wind exposure, optimize landscaping and drainage, and maximize the potential for the use of small-scale renewable energy sources like solar and wind. It would also include the use of the least energy-intensive construction methods, the use of most environmentally-benign and least energy-intensive materials, and an emphasis on applying simple solutions—for instance, increasing insulation values rather than investing in a more complex heating system that will require more maintenance over the long term. In rural areas where indigenous peoples predominate, it is vital to include the input of tribal groups in the design process. CCHRC's newest project, begun in January 2008, is the construction of two practical and affordable rural Arctic homes that will demonstrate the best building design practices and materials available, maximize energy and water efficiency, and also incorporate the traditional knowledge of Alaska Natives for whom the houses will be built. This project will realize many of the goals and strategies emphasized at the Northern Sustainable Shelter Forum, and provide an important example for future rural Arctic construction.[122]

Given the large number of inefficient buildings currently in use, it is certainly not feasible to demolish all of them and completely rebuild. Incremental improvements and retrofitting, therefore, must play a large role in reducing energy use in Arctic structures. If they cannot include redesign of the whole building, these efforts should focus on insulation and energy-efficient appliances rather than more complicated technological solutions. Simple solutions are usually the cheapest and the easiest to maintain. CCHRC enjoys a large of amount of support from the building industry in Alaska, indicating that builders in Alaska, and throughout the Arctic, are concerned about energy use and willing to change old habits.

R&D- Building design and technology have made significant progress over the last few decades, and "net-zero-energy" buildings are now achievable, though they are expensive and require careful planning and implementation by knowledgeable architects and builders. Further research and development of materials and techniques is needed in order to make net-zero-energy buildings economical and to promote widespread adoption of the necessary building practices and materials.

Infrastructure Needs- There is considerable institutional inertia to be overcome in order to implement more efficient and sustainable building standards. First, building codes must be strengthened, and updated regularly, in order to keep pace with the development of better building techniques. Second, planners and architects and builders must be educated, and must communicate, about the industry "best

[122] See the CCHRC website: http://www.cchrc.org/research.html.

practices" so that they can be put into use as quickly as possible. If any of the three groups fails to adopt more energy-efficient goals and methods, the beneficial effect of the practices is weakened. Fortunately, the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) standards provide a widely accepted benchmark for specific best practices, and only implementation lags behind. Widespread retrofitting will occur only after consumers are educated about the cost savings possible, but once this happens there will be a greater need for technicians, auditors, builders, etc. Community colleges and vocational-technical institutes in many cases provide the ideal place for such training.

Implementation Costs- Costs vary for retrofitting and energy-efficient building practices, but these actions will not be taken unless the extra initial investment is repaid within a specified period of time, though this period can vary from a few months to several years. In Alaska, the Alaska Housing Finance Corporation (AHFC) provides significant numbers of low-interest loans annually to homeowners who can benefit from better insulation, appliances, etc., and also to people buying a home that exceeds the Alaska Building Energy Efficiency Standard (BEES)—an important service in the Arctic.[123] As mentioned above, good building practices can have benefits beyond energy savings, because they can contribute to rendering a community more attractive as a whole and thereby increase quality of life and entice new residents and visitors.

Timescale- Though practices and materials are constantly improving, the knowledge and technology exist today to dramatically increase the efficiency and reduce the carbon footprint of new and old buildings. However, the construction of net-zero-energy buildings will likely not become common for perhaps two decades. Thus, it is vital that new buildings be held to a high energy efficiency standard and that retrofitting continue to improve the efficiency of old buildings.

Federal Programs- Though the federal government does not offer any Arctic-specific programs, it does support low-income weatherization programs and building research programs. In the CCTP, these programs include research in: integrated and "intelligent" building systems, building envelope, advanced energy-saving technology like "smart roofs" and on-site fuel cells, and better building design tools (e.g. computer software) that enable a holistic approach to design. It also funds the Energy STAR program, which awards a special label to electrical appliances that are especially efficient and seeks to encourage industry to develop more efficient models. The CCTP's stated goal for building efficiency is that net-zero energy systems be marketable for residential buildings by 2020, and for commercial buildings by 2025.[124]

[123] See AHFC website: http://www.ahfc.state.ak.us/energy/energy.cfm.
[124] *U.S. Climate Change Technology Program Strategic Plan 2006*, p. 64.

The recent Energy Security and Independence Act of 2007 mandated that all federal buildings reduce their energy use 30% by 2015, and that new or renovated federal buildings reduce fossil fuel use 55% by 2010 and eliminate fossil fuel use by 2030.[125] These ambitious targets and the high energy use per capita in Alaska provide an opportunity for the federal government to demonstrate its commitment by constructing a facility in a cold climate that uses no fossil fuels and shows high overall energy efficiency. Such a project would set a strong example for other federal and non-federal projects.

Short- and Long-term Benefits- In the short term, better buildings can provide the immediate benefit of energy efficiency and therefore cost savings and also expanded job opportunities in the building sector. But the implementation of better practices, more importantly, holds the promise of contributing to a general long-term commitment to sustainability and a less carbon-intensive lifestyle in the Arctic.

[125] EERE Network News (1/2/2008): http://www.eere.energy.gov/news/archive.cfm/pubDate=%7Bd%20%272008%2D01%2D02%27%7D.

5) Methane Hydrates and Carbon Capture and Storage

The extraction of methane hydrates and the use of carbon capture and storage (CCS) technology have both benefits and drawbacks. They allow humans to continue to use convenient fossil fuels while reducing carbon emissions, but they also prolong dependence on fossil fuels and contribute further emissions. However, since it currently appears that non-fossil energy sources will not be able to completely replace fossil sources in the short term, these two strategies may provide more time for the development of alternative energy sources and greater energy efficiency.

a) Methane Hydrates

Methane hydrates, found in large concentrations in the Arctic, are a fossil fuel, and their combustion entails all the GHG emission problems of fossil fuels. However, they represent an opportunity for the U.S. to continue using fossil fuels to buy time for the development of greater renewable energy capacity. Worldwide estimates of methane hydrate resources approach 400 million trillion cubic feet, with U.S. resources concentrated in the Gulf of Mexico and Alaskan Arctic and numbering between 113,000 and 676,000 trillion cubic feet.[126] Methane combustion produces significantly less carbon dioxide than combustions of other fossil fuels such as oil and coal,[127] and for every cubic foot of methane hydrate recovered, there can be up to 160 cubic feet of combustible methane recovered.[128]

Hydrates form under extremely low temperatures and pressures when gas molecules are surrounded by a cage of frozen water molecules known as a clathrate. When hydrates are extracted and burned, they resemble ice on fire. Hydrates also play a role in carbon capture and storage (CCS) technology, because captured carbon can form hydrates upon its injection into the ocean or ground, where it may be sequestered for a long period of time. Further discussion of this potential will occur in the section on CCS.

R&D- Current research and development on methane hydrates, under the aegis of the Department of Energy, focuses both on the Gulf of Mexico and Alaska's North Slope. A concern with methane hydrate research is the potential for blowouts, which can occur along shallow continental shelves such as that off of Alaska. Thus, while Alaska has far more methane hydrates off its shores, there is also more potential for them to erupt, cause shelf instability and waves, and emit methane. Research should focus on safely

[126] H.R. 1753 and S. 330, Methane Hydrate Research and Development Act of 1999. Hearing before the Subcommittee on Energy and Mineral Resources of the Committee on Resources House of Representatives, 25 May 1999.
[127] NRL press release on methane hydrates: http://www.nrl.navy.mil/pao/pressRelease.php?Y=2003&R=15-03r.
[128] Subcommittee hearing document.

harnessing this energy source while maintaining the stability and integrity of the coastal biogeochemical system; in this regard, the Messoyakha fields in Russia could prove to be a helpful precedent.[129] There is also interesting potential for hydrates' use in remote communities such as Barrow; development of such domestic use could demonstrate hydrate recovery along free gas/hydrate interfaces, a relatively new technology.[130]

While transport options have yet to be explored because of the early stage of hydrate surveying and recovery research, LNG transport may continue to be the best way of exporting this abundant methane source. Oak Ridge National Laboratory (ORNL) is currently conducting research on hydrate formation and dissociation using seafloor simulators that can help both to understand resource extraction and to enhance storage and transport.[131]

Infrastructure Needs- Infrastructure for the development of methane hydrates is already largely in place, due to oil drilling technology in the Arctic. If hydrate instability contributes to coastal erosion, however, physical infrastructure along the coast and for the hydrates' extraction must be strengthened. Moreover, stability research is worthwhile even if its ultimate goal is not hydrate extraction, since hydrate instability (with increased warming) can affect current oil and gas drilling infrastructure.

Implementation Costs- The implementation costs for the research and development and infrastructure necessary to extract methane hydrates are mostly associated with at-sea operations, because the resources are often located beneath the sea floor. DOE funding for natural gas hydrates R&D is $20 million for FY2007, growing by $10 million each year through FY2010; approximately 60% of this funding goes to public-private partnerships.[132]

Feedbacks- Feedback concerns for methane hydrates hinge not only on their status as fossil fuels—therefore as direct contributors, upon their combustion, to the GHG inventory and greenhouse feedback cycle of the atmosphere—but on the danger of blowouts. Research around the continental shelf of Norway has pointed to an ancient continental shelf slide, Storegga, caused by hydrate blowouts, which

[129] Timothy S. Collett and Gabriel D. Ginsberg, "Gas Hydrates in the Messoyakha Gas Field of the West Siberia Basin—A Reexamination of the Geologic Evidence", 1998: http://www.isope.org/publications/journals/ijope-8-1/abst-8-1-p022-JC-184-Collett.pdf.
[130] NETL "Fire in the Ice" methane hydrate newsletter, Spring/Summer 2007. http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/Newsletter/HMNewsSpringSummer07.pdf
[131] Nucleation and dissociation of methane hydrates: http://sps.esd.ornl.gov/nucleationdissociation.html , also the ORNL's methane hydrate website at: www.ornl.gov/info/ornlreview/v33_2_00/methane.htm
[132] NETL ppt on challenges of commercializing methane hydrates: http://www.hartenergyconference.com/hydratemethane06/RBoswell.pdf

created a tsunami that slammed into the present-day British Isles and a period of increased warming.[133] Current seismic data along Alaska's northern coast could point to methane rumblings,[134] though the "clathrate gun" hypothesis so popular among doomsday proponents is highly unlikely.[135] (The clathrate gun theory states that recurring climate warming periods are due to sudden and massive hydrate blowouts.[136]) All blowout possibilities aside, methane hydrate extraction and combustion feedback cycles, as well as their negative consequences, are similar to those associated with any other fossil fuel.

Timescale- The Interagency Roadmap for Methane Hydrate Research and Development, released in July 2006 by DOE, aims to confirm the resource potential by 2010, with production potential by 2015 and large-scale Federal funding terminating in 2020, though the authors acknowledge that production could happen sooner because of demand.[137]

Short-term and Long-term Benefits- Methane hydrates can provide a cleaner-burning fossil fuel source while other mitigation technologies are developed, and should only be used to this end to reduce future warming. Because there are already government programs in place, with budget projections, and because the oil industry has already developed most of the necessary physical infrastructure, methane development is a feasible fuel source in the short-term. While there are large amounts of methane hydrates under the seafloor, they are still a fossil fuel and can contribute to severe global warming. If hydrates are used in the long-term, it is imperative that they be coupled with other mitigation technologies to reduce their detrimental effects on the climate.

b) Carbon Capture and Storage

Carbon capture and storage (CCS) technology is a short-term solution for carbon levels which can support existing infrastructure, and be a helpful addition to any mitigation portfolio. It is meant to accompany fossil-fuel energy production, and requires proximity to fuel production wells to be an effective strategy, so it could be appropriate for parts of the Arctic. CCS is the capture of emissions from conventional power plants or extraction sites, and their injection into the ocean or the ground for long-term storage.

[133] T. Bugge, R.H. Belderson, N.H. Kenyon, "The Storegga Slide", Phil. Trans. R. Soc. Lond.
[134] Phil McGillivary, personal correspondence, 26 July 2007.
[135] "Shooting Methane Blanks" (Science, 10 February 2003): www.sciencemag.org/cgi/reprint/311/5762/737e.pdf.
[136] Gerald R. Dickens, "A Methane Trigger for Rapid Warming?" (14 February 2003): www.sciencemag.org/cgi/reprint/299/5609/1017.pdf.
[137] "An Interagency Roadmap for Methane Hydrate Research and Development," from DOE Office of Fossil Energy, July 2006.

This ground storage can occur in exhausted oil wells, unmineable coal seams, or saline aquifers.[138] The carbon dioxide is collected for injection from production wells or power plants using technologies such as amine scrubbing. Unlike other mitigation schemes, it also offers an accurate measure of how much carbon dioxide is removed from the atmosphere, and what the cost of that removal is.

Globally, there are three main saline aquifer CCS development projects underway: in the Plains states in the U.S., in Germany, and in Norway's Sleipner oil field in the North Sea. The first successful saline aquifer injection field test, and an excellent example of CCS in the Arctic, Sleipner has been operational since 1996 and has sequestered over 7 million metric tons of carbon dioxide successfully.[139] Weyburn in the U.S. has been operating since 1999, and the CO2SINK project in Germany is just reaching operation.

R&D- Sleipner's development appears to have been paralleled by the development of relatively sound seismic sensing technologies, though leakage of sequestered carbon cannot be easily quantified.[140] Better monitoring systems are therefore a research need with CCS technology.

Regarding the CCS technology itself, however, more research is needed on the nature of clathrates: when carbon-based gases are injected deep underground or into the ocean, they form clathrates (like naturally-occurring methane hydrates), and the feedback cycles for clathrates are still poorly understood. This research might tie in with a methane hydrate R&D program.

Direct injection of carbon into the oceans can cause numerous environmental problems. It causes ocean acidification, in which dissociating carbon dioxide molecules increase the acidity of the water. This acidity affects the ecosystem at all levels, from weakening the carbonate exoskeletons of microorganisms to poisoning fish. Therefore, while research on the carbon "carrying capacity" of the ocean might seem worthwhile, because of the increasing amount of carbon in the atmosphere, the carrying capacity will likely be suppressed in the future. Saline aquifer storage appears to be a much better research investment.

Infrastructure Needs- Some of the infrastructure required for CCS already exists because of enhanced oil recovery systems—many fields have for years been the sites of CO_2 reinjection aimed at retrieving greater amounts of crude oil. Capturing technology is also needed, and transport will likely be the largest

[138] See the U.S. CCTP's Strategic Plan, Chapter 6, for a detailed description of coalbed and oil well sequestration: http://www.climatetechnology.gov/stratplan/final/CCTP-StratPlan-Ch06-Sep-2006.pdf.
[139] "CO2 Storage: Opportunities for the E&P Industry": http://www.pttc.org/technology_summaries/statev11no1.htm.
[140] IEA GHG R&D Program: www.co2captureandstorage.info.

infrastructure need for CCS, since the cost of the technology rises steeply as the distance between capture and storage sites increases.

Implementation costs- Carbon economics motivate project development: the chief motivation for beginning Sleipner's CO_2 injection was to avoid paying a carbon emissions tax,[141] and an increase in oil prices could stimulate additional enhanced oil recovery programs.[142] Ultimately, government regulation of carbon or an energy industry consensus on who will bear the cost of CCS will determine its future; currently, the start-up costs associated with the technology are too high to encourage its development.[143]

Geopolitical and Cultural Considerations- The London convention still protects the ocean from many of these technologies, most notably direct ocean injection, though its status with regards to the ocean floor may be changing.[144] Natural formations do not always respect political boundaries (for example, the Weyburn project in the Plains states actually transports carbon dioxide over the U.S.-Canadian border for storage), and both oceans and saline aquifers can cause international conflict when used for CCS. With current debate about the Arctic Ocean floor at the forefront of the political arena, injection could trigger some difficult disputes. The same goes for methane hydrate extraction. CCS technology will also likely meet with considerable opposition from environmental interests because it is largely untested in the long-term and works in conjunction with fossil fuel power sources.

Feedback- Of concern with CCS is the possibility that tons of trapped carbon dioxide will eventually escape. While large-scale CCS technology is in development, and scientists are fairly sure that carbon storage is permanent, only time will tell. Currently, it appears that while carbon and concrete react with brine in storage reservoirs, the means of storing the emissions underground are fairly stable. Studies of their long-term stability are essential, though, if this technology is to be developed further.[145] If CCS maintains its perceived degree of permanence, and research shows that this perception is correct, it should cause few feedback problems. Direct ocean injection causes feedback issues (by suppressing the carbon carrying capacity of the oceans), and hence is not an effective technology in the long term, though it

[141] "CO2 Storage: Opportunities" document, and Beverly Saylor, personal communication, 17 July 2007.
[142] IEA GHG R&D Program website
[143] "Incentives for CO2 Capture, Transport, and Storage": http://www.co2captureproject.org/news/documents/2007Updates/CCP2%20Principles%20CCS%20Incentives.pdf.
[144] IEA GHG R&D Program: http://www.co2captureandstorage.info/docs/METI%20012007/Presentations_WS_on_CB/03_CCS%20status%20&%20confidence%20building%20Tokyo%20jan%202007.pdf.
[145] Defigueiredo, Mark. "The Liability of CO2 Storage" (2007): http://esd.mit.edu/people/dissertations/defigueiredo_mark.pdf.

appears unlikely to generate a feedback that will cause the carbon stored in the deep ocean to well up on a near-future timescale.

Short- and Long-term Benefits- The short-term benefits of CCS technology are that it curbs emissions and can buy time for the development of long-term renewable energy options. It also prevents abandonment of current oil and gas industry infrastructure, while still enabling a shift to other forms of energy production. The long-term benefit of CCS is the flexibility of timescale it affords for the development of renewables.

6) Theoretical Geoengineering

While most geoengineering schemes are informal proposals that remain untested and unrefined, the creativity and scale of polar-specific geoengineering schemes makes them worthy of mention, if not further investigation. There are several types of proposed geoengineering. Some, such as iron fertilization and particulate expulsion, work directly with carbon. Others, like solar shielding, do not directly affect carbon levels. All of the schemes, since they are still purely speculative, would require enormous investments of capital and infrastructure, though they all promise immediate solutions to planetary warming through alteration of feedback cycles. If a state of environmental emergency occurs and geoengineering is the only way of preventing catastrophe, these immediate solutions may be more appropriate for the Arctic than for anywhere else because of the way that climate change is affecting the region drastically and swiftly (and because of the impact that Arctic systems, like sea-ice, have on the rest of the world's ecology). As Stanford scientist Ken Caldeira points out, however, many geoengineering schemes do nothing to lessen the amount of carbon in the atmosphere, but instead provide a cooling effect to buy time for other technological developments.[146] Even geoengineering champion and Nobel prize-winning chemist Paul Crutzen warns that geoengineering is a last-ditch attempt to save the Earth from catastrophic warming.[147] Geoengineering requires an understanding of total Earth systems that the scientific community will perhaps never achieve; any research towards geoengineering must be research toward understanding the effects of altering the climate drastically, rather than research toward understanding how to do so.

a) Solar Shielding

Solar shielding is a proposition for altering the albedo of the Earth by suspending sunshades in outer space or scattering sulfuric particles in the upper atmosphere.

R&D, Infrastructure Needs, Implementation Cost- Solar shielding takes the form of sunshades or stratospheric particulate infusion. Both projects are highly theoretical, so R&D needs cover every aspect of the project. In addition, while NASA likely has the rocket technology necessary to suspend millions of tiny sunshades at the inner LaGrange point, the sunshades themselves need to be built, in the range of a

[146] See Caldeira lab homepage for publications: http://globalecology.stanford.edu/DGE/CWDGE/home/main%20page/People/Caldeira/Caldeira_Research.php#_1

[147] "Albedo Enhancement By Stratospheric Sulfur Injections: a contribution to resolve a policy dilemma?" (Crutzen, 2006): www.springerlink.com/content/t1vn75m458373h63/fulltext.pdf

few trillion dollars.[148] Any particulate injection scheme, as well, would require infrastructure and research, and also be very expensive.

Geopolitical Considerations- The geopolitical considerations of solar shielding are enormous. Any solar shielding scheme would have to be an international undertaking, unless particulates were injected into the upper atmosphere on a very local level—something difficult to control. Doubtless, injecting particulates into the upper atmosphere could be misconceived as an act of aggression. While climate change is a global issue with global contributions, an international mitigation scheme to the extent of proposed solar shielding schemes would involve astonishingly complex negotiations. This is largely because the gains and losses resulting from this action would be unevenly distributed across the globe.

Feedback- Geoengineering directly impacts feedback cycles. Solar shielding would regulate incident light, affecting temperature and photosynthesis in the Arctic, among other systems. While suspended particulates would alter the albedo of the earth, their fallout might as well, in unpredictable and possibly detrimental ways. Lowell Wood[149] argues, however, that if the injection occurred at a high enough altitude this would not be the case, though there is no proof as to what outcome is likely.

Timescale, Short- and Long-term Benefits- The timescale for the development of solar shielding projects is on the order of a quarter-century[150], though their effects would be immediate. It is also unclear whether the effects of geoengineering are necessarily beneficial. There is no long-term aspect to geoengineering, save for the development of other mitigation technologies which might occur during an engineered period of cooling.

b) Expulsion of Particulates

Geoengineering schemes are usually the result of one man's musings; Al Wong, a UCLA physicist, is responsible for the idea to export carbon into outer space via the Van Allen belts. Because of the shape of the Earth's magnetosphere, the Arctic is the ideal launching spot for carbon. Current questions in the research and development of this idea hinge on energy efficiency and the feasibility of a heavy ion like CO_2 being catapulted into space—it may take more energy to export the carbon than would be mitigated. This technology has not been subject to pilot-project testing, and experimentation could prove overly expensive or harmful.

[148] "Solar Shield may save the planet": http://news.com.com/2300-11397_3-6132879-1.html.
[149] www.rollingstone.com/news/story/12343892/can_dr_evil_save_the_world/1
[150] "Solar Shield may save the planet"

c) Iron Fertilization

Iron fertilization refers to the dumping of iron sulfate into the ocean to increase plankton growth. It is designed to enhance algal blooms in nutrient-deficient waters. In theory, phytoplankton enhance the carbon sink of the world's oceans by taking up carbon dioxide during photosynthesis.

While the direct link between iron and plankton blooms has been well-established, there has been little large-scale experimentation, and that which has occurred points to iron fertilization being ineffective in the long term. The Southern Ocean Iron Fertilization Experiment (SOFeX) served as a good large-scale demonstration of the technology in the relatively barren Southern Ocean. However, a recent wealth of research shows that because of increasing atmospheric carbon levels, the carbon uptake of the ocean is affected regardless of the phytoplankton's contribution.[151] The potential of this technology in the Arctic is very little, despite the importance of sea-ice algae to the Northern ecosystem, says Dr. Josefino Comiso of NASA's Goddard Space Flight Center.[152] In addition, there is considerable international controversy over fertilization technology, given the London convention's prohibition on ocean dumping and the EPA's ongoing investigation of the California-based company Planktos' marketing of carbon credits in exchange for iron dumping. Because of iron fertilization's limited long-term effectiveness and potential harm to the environment, the low sequestration potential of the Arctic Ocean, and issues of legality, iron fertilization is an unattractive option for Arctic carbon mitigation research.

[151] http://daac.gsfc.nasa.gov/oceancolor/scifocus/oceanColor/iron_limits.shtml
[152] NIC and USARC Ice-Diminished Arctic conference poster abstract, and personal correspondence (7/16/2007).

Conclusion

This report began with the assertion that humans must take active steps to mitigate the effects of climate change. The length of the preceding sections is a testament to the fact that there is a lot happening in the Arctic right now—scientifically, technologically, socially and environmentally—and that the Arctic can indeed play a very important role in developing and implementing a coordinated and effective national policy for climate change mitigation.

The U.S. mitigation portfolio, it is now well-established, must tackle a multitude of challenges simultaneously. In order to achieve maximum impact, it must recognize the interconnections between issues and address them holistically. These interconnections can be glimpsed throughout this report: growing scientific knowledge of manmade climate change leads to research on natural carbon cycles, rising renewable energy production necessitates improvements in the existing fossil fuel-based grid infrastructure, increased need for energy efficiency prompts the development of better building and land use practices, and so on.

There is no longer any doubt that climate change, especially in the Arctic, will pose serious threats to the environment, human infrastructure, indigenous cultures, and to the carbon-intensive typical U.S. lifestyle. Responding productively and commensurately to the danger will require an unwavering commitment to broad policy initiatives, targeted technological and scientific advances, and personal- and community-level education and action, all while remaining focused on the greater purpose—leaving the best world possible for future generations.

Despite its reputation as distant and desolate, the Arctic is a region teeming with diverse ecosystems, complex natural cycles, significant resources, and vibrant human communities. This report has attempted to show that it is a region still poorly understood, but which simultaneously has a great impact on climate change throughout the rest of the world—on factors like sea levels, ocean currents, and the amount of carbon sequestered in plants and soils, to name a few. It is therefore vital that the future research projects listed below be given the proper priority.

Not merely a "canary in a coal mine," the Arctic promises to be a key site for investigating and testing a variety of carbon mitigation strategies, all of which may make a significant contribution to the "mitigation portfolio," and many of which could be adopted in other regions. As mentioned before, because of the unique conditions present in the Arctic, many of the strategies discussed here—geothermal power, wind-diesel hybrid systems, improvements in building design and practices, methane hydrate extraction, forest and peatland management, CCS systems, etc.—may become or already have become feasible in the Arctic earlier than elsewhere. For all these reasons, Arctic research deserves to be a central part of any national climate change mitigation strategy. And as the threat posed by climate change continues to grow, so will the importance of Arctic research.

Recommendations for Future Arctic Research Projects

What follows is a summary of recommended Arctic research projects that together have the potential to take advantage of the unique conditions in the Arctic while furthering the goals of climate change mitigation. For each of the six major areas discussed in the report, and for each subsection within those areas, a list of projects is given. Of course, all of these projects should be developed in the context of international partnerships and collaboration.

1) Monitoring

One of the first and most important steps in assembling a wise portfolio of Arctic carbon mitigation schemes is to develop a better understanding of the Arctic carbon cycle, of Earth systems, and of the likely consequences of future climatic changes. That broad goal will be supported by a number of specific studies.

i) Continued support of the AON and the integration of monitoring systems (as Australia is doing with its "Forest Network" project)

ii) Greater integration of high-resolution remote sensing systems and more widespread in-situ monitoring systems

iii) Research on nutrient (especially carbon and nitrogen) cycling in taiga and tundra ecosystems, as well as a more complete study of feedback systems

iv) Research on what receding ice means for algae and the Arctic food web, as well as for carbon storage

2) Fostering Carbon Sinks

Besides monitoring of environmental change in the Arctic, there is a great need for better understanding of carbon sinks and how humans can manage them and even enhance their absorption of carbon.

i) Study of Northern soils, forests and oceans to determine whether they are net sources or sinks of carbon, and how to shift the balance favorably

ii) Investigation of the implications of an advancing treeline and/or agricultural zone

iii) Use of geoengineering models to better understand Arctic feedback cycles

iv) Improvement of burn tactics and growth management systems for Northern forests

3) Modification of Point-Source Energy Production Methods

In order to become a less carbon-intensive society, it is vital that non-fossil energy production methods be developed and widely implemented. Many opportunities exist in the Arctic.

a) Geothermal Power

i) Further tests of advanced sensing systems for locating geothermal resources, and of improved exploratory drilling techniques

ii) Investigation of potential for local (off-grid) geothermal energy systems in the Arctic, similar to the one at Chena Hot Springs Resort

iii) Investigation of larger-scale, long-term EGS systems in the Arctic, perhaps coupled with carbon storage technology

b) Hydroelectric Power

i) Further studies of the feasibility of integrating micro-hydro projects with diesel generation in rural communities

ii) Development of methods for overcoming cold climate issues affecting Arctic micro-hydro projects

c) Wind Power

i) Development of energy storage mechanisms and turbine designs appropriate for Northern climates

ii) Refinement of reliable wind-diesel hybrid systems

iii) Development of local infrastructure for the manufacturing, distribution, installation, operation and maintenance of wind turbines in the Arctic

iv) Drafting and implementation of regional wind energy plans where they are beneficial

d) Solar Power

i) Investigation of solar power as part of a hybrid renewable energy system, such as the Hybrid Micro Energy Project at CCHRC in Fairbanks

ii) Development of solar water heaters and other energy-saving applications

e) Wave, Tidal and Osmotic Power

i) Establishment of research and development center for Arctic ocean energy projects

ii) Investigation of how to make wave energy development feasible in Alaska

iii) Aggressive pursuit of tidal energy development in Cook Inlet

iv) Preliminary study of possible osmotic power resources in Alaska

f) Biomass Power

i) Large-scale study of the feasibility in Alaska of biomass-fueled systems for electricity and heating (perhaps district heating)

ii) Testing of hybrid power generation, combining biomass and other renewable sources

iii) Demonstration of a large-scale biodiesel manufacturing facility in Alaska

iv) Investigation of further methods for extracting energy from municipal waste, especially those that could be cost-effective in smaller Arctic communities

g) Hydrogen and Fuel Cell Technology

i) Study of the feasibility of intermittent renewable power sources connected to hydrogen storage systems, with a demonstration project

ii) Investigation of the export of energy generated by renewable sources, using hydrogen

h) Nuclear Power

i) Careful observation of the Galena nuclear project's safety and cost-effectiveness

ii) Investigation of other suitable Arctic locations for small-scale nuclear power (if the Galena project is successful)

4) Energy Conservation and Efficiency Measures

Energy conservation and efficiency will be more important than ever as the Arctic and the world adapts to the challenges of climate change. Because of particularly high energy costs and awareness of the dependence on energy for survival in a harsh climate, the Arctic could well adopt many of these measures before other locations.

a) Personal Conservation and Efficiency, and Community Planning

i) Large-scale education campaigns about energy and the environment, the need for conservation and efficiency, and how to conserve

ii) Establishment of central information source where Arctic citizens can learn how to conserve

iii) Development and implementation of community energy plans in all Arctic communities

iv) Study of how to incentivize sustainable local policies (e.g. land use planning that discourages "sprawl" and highly energy-efficient building codes)

v) Study of the "best practices" from other Arctic nations

b) "Smart Grid"Technology

i) Investigation of the large-scale implementation of "smart grid" systems in the Arctic, particularly those that give consumers information about their energy use (e.g. prepay meter systems)

ii) Comprehensive study of the how to ensure that Arctic grids can successfully integrate new renewable energy projects and local CHP systems, including the need for energy storage mechanisms

c) Combined Heat and Power Systems

i) Large-scale study of the feasibility of biomass CHP for power generation, heating, and district heating in Alaska, perhaps combined with other renewable energy sources

ii) Demonstration of large- and small-scale CHP system applications in Arctic conditions, especially diesel engine heat recovery systems

d) Building Design and Practices

i) Central information source and standardized training program on sustainable building practices for Arctic planners, architects and builders

ii) Further demonstrations of energy-efficient, sustainable Arctic building designs, e.g. a federal facility that uses no fossil fuels and achieves net-zero energy use

iii) Research and development of better materials and construction equipment for Arctic structures—insulation, windows, etc.

iv) Investigation of effective methods for incorporating the input of indigenous peoples

v) Study of the "best practices" of, and cooperative demonstration projects with, other Arctic nations

5) Methane Hydrates and Carbon Capture and Storage Systems

Methane hydrates and carbon capture and storage systems take advantage of the existing oil and gas industry infrastructure, while reducing carbon emissions and allowing time to further develop less carbon-intensive forms of energy production, especially renewable sources.

a) Methane Hydrates

i) Further research on the stability of methane hydrates and their feasibility as a Northern energy source and as an export

ii) Study of the need for infrastructure strengthening in the Arctic because of methane hydrate instability and extraction

b) CCS Systems

i) Study of coupling CCS with existing Arctic production wells (because of the advantage of short distances for CO_2 transport)

ii) Research comparing the economics of CCS in the Arctic under either a carbon tax or a cap-and-trade scheme

iii) Demonstration of the long-term stability of underground carbon storage

6) Theoretical Geoengineering

Since geoengineering schemes are inherently uncertain and risky, and because they are only to be deployed in dire circumstances, large-scale testing appears to be unrealistic at this point. However, they do merit some further consideration.

i) Further study of the feasibility of solar shielding and expulsion of particulates

United States
Arctic Research Commission

July 23, 2008

Author's direct contact:
Mead Treadwell
(907) 223-8128

C.H. "Bud" Albright, Jr., Under Secretary
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Bud,

Thank you and Doug for taking the time to meet with me while you were in Alaska. Barely 30 minutes after Senator Murkowski had told me you were in her office, we got together. That's fast work!

I write concerning the future of DOE's Arctic Energy Office. The U.S. Arctic Research Commission is a strong supporter of the program, which dates to 2001, as part of DOE's National Energy Technology Laboratory. Much of the Arctic Energy Office's work is paying off in facilitating greater fossil energy production in the U.S. Arctic. On behalf of the Commission, we urge the DOE to allow the Office to be able to support research activities in the areas of non-fossil fuels/alternative energy, in addition to its current focus on fossil fuels.

The Commission is seeking this change for several reasons. First, we believe DOE should be working all forms of energy development in the Arctic as part of an integrated program. Arctic residents must choose between all types of fuels and power sources to meet their needs. With hundreds of communities "off grid" in the U.S. Arctic, and – we are told – close to 2000 communities "off grid" in other parts of the Arctic, enabling appropriate choices for power and energy use will help these communities survive. Energy costs are much higher in this part of the world, and applied research on new techniques can have a faster, sustainable payoff for all Americans when Arctic communities are used as a laboratory.

Second, we believe research on all Arctic options can play an important and beneficial role to both energy security and reducing the world's carbon footprint. A new USGS review of Arctic oil and gas potential is soon to highlight this part of the world. Our hydro, wind, coal, geothermal, estuary/osmosis and wave energy potential is significant. Mother Nature has some of her biggest carbon sinks in the Arctic. New mitigation techniques may also take advantage of the Arctic's unique features, including cold ocean water, deep permafrost, gas reservoirs, or – as I mentioned when we met – the high-latitude magnetic features of the Earth.

There are several ways this objective might be reached. Ideally, as you and I discussed, the Office would report directly to the Office of the Secretary. (That approach, which we prefer, was contained in the draft colloquy I left behind with you, in language prepared for Congressional floor debate earlier this year.) Without an organization change, an order on your part could simply remove the fetters from the program. At the same time, you could direct the office to tie DOE's Arctic Research goals into the President's Climate Change Technology Program as well as the basic science being conducted by DOE in the Arctic as part of the Climate Change Science Program. The office might serve as a clearinghouse for funding research conducted by other laboratories of DOE, even as it keeps its funding base in fossil fuels.

Either of the latter two options could be announced by DOE alone, or perhaps brought about by agreement with the Commission and the Interagency Arctic Research Policy Committee. The Interagency Arctic Research Policy Committee is committed now to producing an Arctic research plan on infrastructure issues (including energy) throughout the government, per the Commission's recommendation, and the Arctic Energy Office would be an appropriate participant in that plan. Undersecretary Ray Orbach participated in the IARPC May 12 meeting at the National Science Foundation where the U.S. Army Corps of Engineers, Cold Regions Research Laboratory, announced it would take the lead in compiling that plan.

I am in Washington, DC on August 6 and could meet with you and others then if more discussion is needed to bring this change about. The Commission came to this recommendation from discussions we've had in many public meetings with Arctic scientists and residents alike. It is time to lift the limitations on this research program today.

With best regards,

Sincerely,

Mead Treadwell, Chair

Cc: via email, Doug Schwartz

The Under Secretary of Energy
Washington, DC 20585

October 31, 2008

Mr. Mead Treadwell
Chair
U.S. Arctic Research Commission
420 L Street, #315
Anchorage, AK 99501

Dear Mr. Treadwell:

Thank you for your July 23, 2008, letter regarding the Department of Energy (DOE) Arctic Energy Office (AEO). We appreciate the interest you, the United States Arctic Research Commission, and the State of Alaska have taken in this office.

I agree with your assessment that the AEO has made significant contributions in the area of fossil energy investigations and development. We fully intend to continue these efforts. At the same time, we share your concerns about the extreme costs for energy, particularly as it relates to remote Alaskan villages inhabited by native peoples. I have made a decision to immediately establish at least one more full-time position in Alaska to carry out an expanded mission for alternative energy. As we seek to fill this position, the Department will identify an expert from our National Renewable Energy Laboratory who will temporarily relocate to Alaska and make an initial assessment of the challenges and opportunities for deployment of energy efficiency and renewable energy technologies.

Thank you for your letter and your continued support for the AEO.

Sincerely,

C. H. Albright, Jr.

cc: The Honorable Lisa Murkowski
United States Senate
Washington, DC 20510-0203

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The Secretary of Energy
Washington, D.C. 20585

October 23, 2008

The Honorable Lisa Murkowski
United States Senate
Washington, DC 20510-0203

Dear Senator Murkowski:

Thank you for your August 7, 2008, letter regarding the Department of Energy (DOE) Arctic Energy Office. We appreciate the interest you, the United States Arctic Research Commission, and the State of Alaska have taken in this office.

I agree with your assessment that the Arctic Energy Office has made significant contributions in the area of fossil energy investigations and development. We fully intend to continue these efforts. At the same time, we share your concerns about the extreme costs for energy, particularly as it relates to remote Alaskan villages inhabited by native peoples. In response to your letter, the Department is currently identifying an expert from our National Renewable Energy Laboratory who will temporarily relocate to Alaska and make an initial assessment of the challenges and opportunities for deployment of energy efficiency and renewable energy technologies. In the longer term, we plan to establish at least one more full-time position in Alaska to carry out an expanded mission for alternative energy.

Thank you for your support in solving energy issues for all Americans and for highlighting the opportunities for broadening the mission of the Arctic Energy Office. I look forward to working with you on this issue, and I will keep you apprised of DOE's efforts to maximize alternative energy development in Arctic climates.

If you require additional information, please contact me or Ms. Lisa E. Epifani, Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Samuel W. Bodman