Reversing Global Warming

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David Pells, the editor of PM World Journal, has challenged its advisory board to think about the role and responsibilities that project and program managers have with respect to global climate change. This, to say the least, is a non-trivial challenge and likely an increasingly important one. In this paper I have reframed David's challenge to reflect not just addressing climate change but actually reversing it and hopefully some fraction of the damage perhaps already done. This reframing probably reflects my engineering roots and post-disaster experience and belief that we must build back better.

In this paper I will attempt to:

- Outline some of the systems of systems challenges that we will likely face.
- Discuss the emergent nature of both the challenges as well as the potential resultant outcomes.
- Draw attention to some of the driving forces acting both on this system of systems as well as the national and sectoral programs that may emerge to respond to this challenge.
- Highlight some of the feedback loops which may exist or emerge from both apparent and hidden coupling.
- Discuss system of system risks, program risks and where our perceptions and appetite for such risks may change over time.
- Outline some particular challenges for program managers as they are engaged in addressing this challenge.

The work that results from this exercise is far from complete and not intended to represent an endpoint but rather one potential starting point. Much remains to be done by our profession and broader society in general.

Systems of systems challenges that we will likely face

Addressing global climate change represents a significant system of systems problem characterized by:

- Extreme levels of interdependence
- Feedback loops, both known and unknown, with uncertain behaviors and varying time constants
- Broadest possible geographical extent
- Emergent behaviors, compounded by the multiplicity of complex systems and actors.
- Continuous system and system of systems level transitions introduce new and unseen challenges (and opportunities)

- Decision making independence across geography; operational independence of deployed and evolving technologies.
- Disparate linkages and effects with existing social systems (socio-technical; socio-economic; socio-environmental)
- Unequal cost and benefit distribution
- Lack of singular clarity on desired outcome, timeframe, and metrics to measure progress and success.

To provide a framework for these challenges I have adopted an ESPRIT[1] framework previously utilized in evaluating international development and construction projects. Table 1 provides a less than complete summary of some on the challenges we will likely encounter in seeking to reverse global warming.

Table 1
System of Systems Challenges Faced in Reversing Global Warming
Utilizing an ESPRIT Framework

Framework Category	**Challenge**	**Comments**
Economic	Defining the problem	This will likely be emergent and multidimensional
	Unclear prioritization of objectives and actions	
	Inadequate coordination of investments globally	
	Harmonization of multiple systems	Harmonization of renewable energy, energy storage and electric vehicle fleets is one example
	Life cycle benefit optimization	Challenged by both emergent objectives and outcome
	Leverage complexity	
	Law of unintended consequences	
	Non-linear feedback mechanisms	
	Perverse incentives	Well intentioned incentives working against overall goal (suboptimizing)

[1] ESPRIT – Economic, Social, Political, Religious, Intellectual, Technology

Table 1 **System of Systems Challenges Faced in Reversing Global Warming Utilizing an ESPRIT Framework**		
	Systemic risks not understood	New system of systems level risks not understood and assessed
Social	Socio-economic	Realities, tolerances, and perceptions vary broadly
	Socio-technical	Realities, tolerances, and perceptions vary broadly
	Socio-environmental	Realities, tolerances, and perceptions vary broadly
	Scale of behavioral and societal changes	Demand reduction and other social changes underestimated or presumption that more time is available
	Articulation of cross cutting principles	
	Decision making under uncertainty	
	Engaging multiplicity of stakeholders with different and often competing interests	
	Emergent objectives	Multiple, temporal and contradictory objectives at both national and system level
	No single version of the truth (SVOT)	Lack of shared understanding degrades system of system performance
	No common semantic space (common mental models and language)	
	Social Dynamics	Inadequate engagement with stakeholders and society at large
	Timescale	Multi-generation problem and solution
Political	Agreement processes	Lack of central authority limits effectiveness of agreements

Table 1 **System of Systems Challenges Faced in Reversing Global Warming** **Utilizing an ESPRIT Framework**		
	Aligned, consistent leadership	Change points become convenient political battlegrounds retarding progress
	Leadership in a multi-political (nation state) environment	
	Legal and regulatory	Alignment with broad objectives while addressing transitional needs
	Workforce dislocations	
Religious (including cultural)	Climate change views reflect or are influenced by religious or cultural views or belief sets.[2]	Deep cultural beliefs are often resistant to fact-based arguments especially when the fact base is challenged
	Shared ethical objectives	
Intellectual	Fact base and interpretation not universally accepted	
	Inadequate trust in science	
	Governance under emergent objectives	Program enabling processes must reflect emergent objectives
	Inadequate innovation in solution set development (new ideas are required)	
	Engaging (versus managing) complexity	
	Inadequate/inefficient knowledge sharing mechanisms	Driven by objectives of competitive advantage
	Tipping points	
Technology	Transition of existing installed base of major systems	

[2] How Religion Impacts American's Views on Climate Change and Energy Issues; Pew Research Center; October 22, 2015

Table 1 **System of Systems Challenges Faced in Reversing Global Warming Utilizing an ESPRIT Framework**		
	Effective output measures not easily linked to outcomes metrics	
	Accelerating to scale (development and deployment cycles)	
	Introduction of new failure mechanisms in systems undergoing transition	
	Increased requirement for self-adaptive systems	
	Inadequate or absent common semantic space	
	System and system of systems level configuration management inadequate for tasks at hand	
	Technology development and disruption	

As we consider the scale of this system of systems challenge it is worthwhile highlighting some of the systems which are constituents in this broad endeavor. They include:

- Economic – funding and financing systems for transformation; subsidies and support for change and dislocations
- Social and Community – jobs, standard of living, engagement
- International Trade and Agreements – principles, goals, commitments, and enforcement mechanisms
- Political – systemic changes required to sustain focus on multi-generational goals.
- Energy – extraction, generation, storage, transmission (pre- and post-generation) and efficient usage and temporal profile
- Transport – alternatives and modes, motive power and energy source, required infrastructure, usage and temporal profiles, resilience and sustainability.
- Industry and manufacturing – energy sources and efficiency, materials, by-products, and waste streams
- Water Infrastructure – potable, process, storage, transmission, flood and coastal management; hydropower
- Built Environment – commercial, institutional, and housing.

- Health and Education – changed demands for services and skills (STEM)
- Agriculture and Land Use
- Resource, Waste and Greenhouse Gas Management – resource extraction, utilization, and optimization; waste stream minimization and reuse; greenhouse gas removal
- Management – systems and approaches to deal with global scale challenges.

Emergent nature of challenge and resultant outcomes

Reversing global warming is faced with a set of emergent challenges as well as a range of potential emergent outcomes. A recent example of an emergent challenge was the withdrawal by the United States from the Paris accord and the reversal of this decision by the subsequent administration. The prospect of future on again off again political reversals must be considered a real possibility, and not just for the United States.

Another example of a recently emergent challenge was driven by the pandemic during 2020. During this period, we saw a broad drop in economic activity globally as various shutdown and quarantine measures were implemented. Carbon emissions were reduced by an estimated 17% but global CO_2 concentrations continued to increase. This has reinforced some skeptical views that climate change[3] is not a man-made phenomenon.

But just as challenges will be emergent so will opportunities, especially as economic and technological tipping points are reached. Examples of some emergent opportunities include:

- UK acceleration of its Net Zero goals from a previous 80% reduction target and the coupled policy actions
- Australia's focus on exporting "sunshine" through renewables-based ammonia production.
- Norway's nod to the 'Longship' Carbon Capture and Storage (CCS) project, a first at scale
- Growing acceptance and acceleration of offshore wind along portions of the US east coast
- US proposal to shift its federal vehicle fleet to an all-electric fleet as they are replaced providing support for the growing industrial base for EVs.

The complexity of the global warming challenge and the system of systems nature of its solution suggests that the desired outcomes and the paths towards them will be emergent. There is no singular solution and even the desired outcomes may shift as progress is made. The multi-finality of this problem suggests many paths are possible. These paths encompass:

- Demand reduction (of greenhouse gas producing activities)
- Improved efficiency (of greenhouse gas producing activities)
- Substitution (replacement of greenhouse gas emitting activities with non GHG activities and processes)

[3] Global emissions of methane reached the highest levels on record driven primarily by growth of emissions from coal mining, oil and natural gas production, cattle and sheep ranching, and landfills.

- Atmospheric removal of carbon (and other GHG)

In each broad category a wide range of paths exist including such things as stopping global population growth; mandatory vegetarianism; power and transport fuels replaced by hydrogen (ammonia) and electrons; and global scale atmospheric carbon capture and storage. As these examples demonstrate, path choices may vary across the globe.

Outcomes from any effort to reverse global warming will similarly be emergent. Leaders will move ahead based on science and conviction and a willingness to translate any short-term pain they may experience into a national competitive advantage. We see some of these attributes in the UK acceleration of its Net Zero efforts. Conversely, laggards will challenge the science, study implications ad nauseum, challenge others to move first or faster, and likely pay for their delayed response in economic competitive disadvantage.

In terms of measurable outcomes with respect to reversing global warming we may find these goals themselves to be emergent as we confront:

- Potential effects from huge carbon, methane and heat sinks and already established trajectories.
- Increased emissions of nitrogen and oxygen from ammonia and electrolysis processes
- Free riders gaining short term competitive advantage.
- Political instability from various dislocations
- Emergent concerns of overshooting (creating a new ice age)
- Implications of new technologies and global economic[4] and social models

Importantly, control mechanisms that focus on initial conditions and compliance of activities to plans are not as effective as are control mechanisms that direct behavior to certain goals and incentivizes simple rules for the emergence of desirable behavior.

Driving Forces

Driving forces that will act to accelerate efforts on reversing global warming will be as much economic and political as they will arise from a concern about the health and well-being of the planet and its denizens. These driving forces will shape not only what is done but how those efforts will be governed and managed. In many ways' climate will become a new battleground for superpower supremacy as they seek to carve out large shares of the resultant impacts and effects.

These include:

- Capturing significant shares of the $2 to 4 trillion dollars in annual investment likely required to move towards Net Zero.

[4] Current rate of electricity consumption by bitcoin miners is estimated to be 0.08% of total global electricity consumption.

- Gaining the advantages, more broadly, from the significant annual investments in research and development that will be required[5]
- Shifting from energy sufficiency and independence to energy supremacy, a true "power"
- Supply chain leverage and attendant economic dividends
- Changing international trade patterns driven by climate policy, perceived leadership positions, and access to critical materials (trade restrictions) or end markets
- Effectiveness and extent of a "climate financial market"

Other driving forces include:

- Securing critical rare raw materials (Lithium, Cobalt, Nickle) in sufficient quantities will drive geopolitical activities and conflicts.
- Developed versus developing world income gap.
- Developing world urbanization rates
- Frequency and extent of extreme climatic events
- New innovations in gene modification (in plants and phytoplankton) and other biology-based approaches (enzymes to facilitate carbon fixation outside of cells) to promote carbon sequestration.

Possible Feedback Loops and Hidden Coupling

Numerous potential feedback loops potentially exist in reversing global warming and even more have yet to be identified. Feedback loops exist within individual systems, each complex in their own right, and many more will exist across systems representing system of systems feedback loops. Potential feedback loops would include:

- **Economic dislocations reduce the appetite for the needed changes, their timing and extent**. For example, the anticipated energy transition from carbon-based fuels to renewables that is already underway may accelerate as the result of strengthened global commitments to decarbonization. Attendant unemployment and economic dislocations become politically unacceptable.

- **Sharp political swings in energy policy related to decarbonization result in lost political influence and policy setting as free market factors guide energy company actions**. We have already seen energy majors continue to move away from carbon-based fuels irrespective of more pro-carbon policies during the last US administration. This has been driven by increased investor focus on ESG and the shifts in market capitalization away from carbon-based players to renewables players. The market cap of the largest renewables companies already has surpassed the market cap of their oil equivalents.

[5] Estimated at $100 billion annually.

- **Reduced oil demand drops prices to levels which discourage lesser developed countries from making required changes to reduce global warming**. Their failure to act becomes a counter argument in developed countries.

- **Global warming trends already in motion unlock greenhouse gases trapped in previously frozen tundra**. Warming creates feedback loops that encourage destabilization of tundra ecosystems and the release of methane from deteriorating permafrost. This further drives the thawing cycle, while higher temperatures drive vegetation, changing soil temperature and preventing snow from reflecting heat.

- **Ocean heat sinks which have stored up to 90% of excess heat trapped by anthropomorphic greenhouse gases grow to even more significant levels, driving more rapid ocean warming, sea rise and hurricanes**. Reversing global warming will not occur over night and ocean warming will disproportionately continue. Coastal flooding will create severe challenges for population centers along the world's coasts, diverting required financial resources from climate change to resilience. Strengthened hurricanes will not only be more frequent and create even more damage but may put some offshore wind energy in danger. Changed current patterns will create new deserts and tropics potentially significantly impacting global food supply. Reductions in atmospheric temperatures will be tempered as heat is rebalanced between the ocean and atmosphere.

- **Shifts to a hydrogen energy system, using ammonia as an energy storage and transport solution, will provide great advantages but create new challenges with respect to oxygen and nitrogen releases to the atmosphere**. Will increased nitrogen releases as part of an ammonia cycle contribute to greenhouse gas effects as it moves concerns from carbon to nitrous oxides?

- **Do accelerated shifts (either those underway or desired) create increased global exposure to new disease pathways impacting global health and population levels**? Will a climate driven pandemic cause a significant reduction in global population reducing demand for greenhouse gas producing food, materials, and energy?

- **Demand for key renewable materials (lithium, cobalt[6], nickel) drive new regional conflicts with the potential to degrade into a limited superpower conflict**.

- **Digitalization of society creates growing energy demands that impact the rate of energy transition**.

[6] More than 70 percent of the world's cobalt is produced in the Democratic Republic of the Congo (DRC)

- **Temporal dislocations between action and effect create challenges in sustaining commitment and investment**. Lags of years to decades can be reasonably expected between meaningful actions and measurable results (thermal inertia; random variations; ecosystem resilience; social resilience; denial; missing governance structures; social resistance; investment lags; research and development lags; carbon cycle inertia; diffusion of innovation; sink flow reversals/search for equilibrium). This is further compounded by natural background variations and the previously described existence of significant sinks.

- **Reforestation efforts are negatively impacted by climate trends already underway** New areas suitable for afforestation must compete with agricultural uses similarly affected by global climate change. Biodiversity and ecosystems are also affected. Political factors that arise limit agility of response.

- **Direct air capture of carbon technologies, while providing benefits, delay shifts in materials and fuels industries**. Apparent net zero cement, plastics and fuels are found to not have fully accounted for carbon from extraction. Availability of some net zero materials delays shift to alternative carbon neutral or negative ones.

- **Strategies to address global sea rise destroy wetlands reducing an important global carbon sink.** Land use policies do not recognize the needs and opportunities associated with land use in coastal zones.

- **Strategy mismatches develop across systems and regions.**

Each of these potential feedback loops as well as those not articulated or yet discovered create unique governance and management challenges for the various programs that will be required to move towards this global paradigm shift. Forward looking metrics focused on second and third order changes will be required and emphasis on innovation and continuous improvement are core attributes of any such efforts and their management.

Risks and Risk Appetite

The challenges posed by reversing global warming are great, weakly understood at best, with different time constants and a myriad of mismatches, and changing both by our actions and inaction. As such the risks we face are uncertain at best and in some instances unknown and potentially unknowable until they fully manifest (true Black Swans).

Yet we are faced with a herd of Black Elephants growing in size and danger with each passing day. Addressing this herd will result in missteps and potential loses, some likely significant. But inaction could result in complete loss.

In addressing global warming, we need to adopt a risk appetite that recognizes the high degree of uncertainties that we face and accepts that failures and unintended consequences along the way are inevitable. This appetite must include a healthy dose of acceptance of these realities but also mechanisms to learn, transparently, and fail forward.

The metrics by which we assess risks themselves will evolve as we know more about the Black Elephants we face, the intervening terrain, and the sharpness of our own spears and the improvements they will require.

The base against which we measure risks itself will be changing and as such this continuous reassessment of risk will act to redefine desired outcomes, rates of action and reweight tradeoffs against other societal risks. New risks, previously unseen or underappreciated both within the global warming domain but more likely in the broader system of systems, will emerge and include likely concerns about "overshooting".

Risk and risk perception, therefore, becomes an important feedback loop.

Challenges for Program Managers

How are we to manage in a dynamic risk environment unlike one which we have ever faced? Risk modeling will require incorporation of evolving assumptions and risk models. Uncertainties may widen long before levels then narrow and sensitivity to the effects of correlation have never been greater. Exposure to emerging objectives and the effects of actions on various systems and the feedback they create will require consideration of new system of system level risks and metrics.

These new metrics will include:

- Risk assessment against a range of potential desirable outcomes
- The probability that emergent strategies will produce desirable outcomes even in light of the uncertainty around what a desirable outcome may be.
- Assessment of potential risk impacts from both known and unknown feedback loops.
- Inclusion of opportunities represented by yet unknown technologies.
- Factoring in future actions and events, not directly related to system of system level concerns, that act to mitigate concerns or extend timeframes for action (significant reduction in global population and activity from manmade or natural events of global scale (regional nuclear war; 21st century Black Plague))

How do we express risk, its range of impacts and probabilities in a system of systems environment?

A second challenge from a management perspective relates to governance of such an endeavor. New governance structures, founded on principles even more so than objectives, will need to exist at a:

- System of systems global level

- National levels
- Individual system levels (energy, transportation, agriculture etc.)

Governance challenges related to equity, social justice, economic dislocations, benefits and burden sharing will grow in importance. Climate may become a new international area of competition creating not just new political blocs but perhaps even more important ideological ones.

High degrees of uncertainty related to causes, mitigation strategies, and required or desired outcomes will challenge governance most broadly but also the ability to commit to sustained action over extended time frames. At what point do we reach "climate exhaustion" similar to the "quarantine exhaustion" experienced during the pandemic.

A third challenge from a management perspective will be a recognition that flows, both their directions and rates, become the dominant control points from a management perspective. Individual projects are important because of their contributions to improving the 'rates' of defined actions but the 'rates' are the real metrics. System level metrics must focus not just on the "velocity" of a system but more importantly on the "acceleration" and "jerk" (change in the rate of acceleration). An open question remains whether these flow measures suffice at a system of systems level or are even higher-level measures of rates of change required to be assessed[7].

Distribution of system of system level flows become increasingly important as we better understand global mixing between hemispheres; atmosphere and ocean; and ocean surface and deep ocean sinks. These distributions will also highlight free riders in any global effort.

A fourth management challenge relates to stakeholder engagement and education. This last point cannot be understated and is given increased importance by the effectiveness of "fake news" efforts. A single version of the truth is desirable, but whose truth? The need for transparency will never have been greater. Importantly, management uncertainties and basis for strategies that are already understood by only a small subset of stakeholders, must now be communicated more broadly. Understanding levels must be improved and engagement in solving the problem or implementing the solution sets will be essential. Management communications must take the complex and reduce the messages communicated to a fourth-grade level.

Finally, we must be prepared to move beyond our current management paradigms and into largely uncharted territories if we are to deal with the challenge of reversing global warming. One of the unique challenges of reversing global warming as a system of systems problem is to recognize that not only are we a part of the "system", acting on it as it acts on us, but that importantly we are only one such actor. We represent just one perspective and there are billions of other perspectives which must be recognized and accounted for.

Our ascertainment of a control strategy and controlling mechanisms is influenced by our singular (or small group shared) perceptions but the effectiveness of any control strategy and mechanisms is

[7] Velocity, acceleration, jerk, snap, crackle, pop

highly influenced by the collective perceptions of others who are part of this system of systems. We must see the world through their eyes as well.

As our individual and collective perceptions shift so must our control strategies and mechanisms. This requires a form and level of engagement not typical in large programs and at an even greater scale.

Program managers have much to bring to meeting the challenge of reversing global warming if we are prepared to think deeper and broader and recognize that all of us are better than any one of us. While policy, principles and technology may reside in the domains of others, management of these efforts will most assuredly reside in ours.

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Bob is an Independent Member of the Shareholder Committee of Mott MacDonald. He is a member of the ASCE Industry Leaders Council, National Academy of Construction, a Fellow of the Construction Management Association of America and member of several university departmental and campus advisory boards. Bob served until 2006 as a U.S. presidential

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