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Biofuels: From a win-win solution to a wicked problem?

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Abstract:

Current and recent struggles encountered in the development of the transport biofuels sector indicate a significant change in the perception of biofuels. Instead of a win-win solution, transport biofuels have become a major planning challenge. In fact, biofuels can be labelled a wicked problem. The planning studies literature offers some tools to interpret this change and guide future actions. First, by assessing recent experiences of biofuels in the EU and US against the ten characteristics of wicked problems we find biofuels "fit" the profile of such issues. Second, we observe that differentiated strategies will suit the different challenges facing biofuels development. We argue that without recognition and engagement of multiple perspectives on transport biofuels they will remain a wicked problem and we therefore advocate for strengthened approaches to communication and engagement.

Key Terms:

Wicked problem: Public policy problems for which no agreed-upon solution is identifiable can be called "wicked". Pursuing solutions is more of a political than a technical exercise. Examples of wicked problems include climate change and sustainability.

Tame problem: Widely agreed upon problems for which the most efficient solution can be identified and pursued can be labeled as "tame". Problems of natural sciences and engineering often fall into this category, for example, choosing methods of treating wastewater. Some social and public policy problems are also tame, for example, installing sewer lines. Pursuing solutions is more of a technical than a political exercise.

Post-normal science: This refers to methods of inquiry for phenomena which are uncertain and contingent on many possible perspectives. Conventional science – traditionally seen as a problem solving exercise whereby repeatable experimental results progress to theory and provide an adequate base from which to make public policy decisions – is insufficient to deal with problems of complex natural and social systems. Post-normal science envisions a peer review role for non-scientists and favours dialogue over proofs.

Win-win solution: This idiomatic phrase indicates that a solution can contribute to solving more than a single problem. Thus biofuels can contribute to mitigating climate change (a "win"), developing the agricultural economy (a "win"), and improving energy security (a "win").

Introduction

In the early 2000s, biofuels for transport were promoted as a sustainable alternative to fossil fuels to reduce greenhouse gas (GHG) emissions, break dependence on oil and thereby improve energy security, and create jobs and opportunities for the agricultural sector. In this way biofuels were said to meet multiple goals and provide a “win-win solution”. However, over the past decade concerns about the production of biofuels have increasingly been voiced with a particular focus on impacts on food production and land use change as well as debates on energy balances and GHG emissions [1-2]. The international biofuels debate is now characterized by a spectrum of positions; at one end are optimistic proponents who continue to argue that biofuels can further be expanded in a sustainable way [3] and at the other end those that call for an immediate stop to the production and utilization of biofuels [4] with a variety of distinguishable positions in between [5-7].

How can one explain the shift that biofuels have undergone? And what does this mean for the biofuels sector? Our efforts to try and understand have taken us to the concept of a “wicked problem” put forward by Rittel and Webber [8] in 1973 to describe the challenge of planning solutions to societal problems. They argued there is a distinction between issues that are relatively straightforward to define, to design solutions for, and to evaluate – which can be called a “tame problem” – versus those that are are ambiguous, value-laden and uncertain. They provide the example of installing running water and sewage systems to homes and argue that this is easier than solving problems of crime or poverty. The term wicked problem has since been applied to many issues including deforestation, climate change, and environmental health risks [9-11] as well as other more positive concepts such as sustainability [12]. In this paper we turn to the wicked problem framework as a heuristic to help analyze if biofuels occupy a new contested, controversial, wicked position and if so, what can be done about it.

We start our analysis by introducing the ten characteristics of wicked problems as defined by Rittel and Weber [8]. Next we map current knowledge and debates around biofuels against these characteristics to support the argument that biofuels have moved from a win-win solution to a wicked problem. This is based on experiences with biofuels from Europe and North America. Finally, we draw on the planning literature and that of other disciplines which have applied the wicked problem framework to provide a new perspective on biofuels. We suggest there is particular value in the notion of "post-normal science" which embraces a role for politics and dialogue in the practice of science [9, 13-14]. Overall, this paper concludes that transport biofuels have moved markedly from a win-win solution to a wicked problem, which means the biofuels community needs to adopt new approaches to communication and planning that emphasize dialogue amongst diverse perspectives.

Background

Rittel and Weber [8] originally outlined ten features of wicked problems. Subsequent authors have adapted these, each emphasizing different aspects [9-10, 12]. In this paper we include the original ten characteristics (see Table 1). It is helpful to think of tame problems as those amenable to the scientific or engineering method, for example, pinpointing the location of food contamination, designing a more fuel-efficient vehicle or correlating a rise in atmospheric gases with global temperature change. These may be very complicated problems to solve but can be made tractable through normal scientific methods of hypothesis testing, observation and experimentation. Wicked problems, on the other hand, are "messy" [15] , characterized by uncertainty, value judgments and disagreements over allowable evidence.

Table 1 – Differences between “tame” and “wicked” problems

Characteristic	“Tame” problem	“Wicked” problem
No clear formulation of the problem	Problem singular and easy to describe. Formulation of problem suggests solution.	Multi-faceted problem, in reality a multiplicity of problems. The process of imagining the problem is critical.
Stopping rule	Planners and policy makers stop when problem is solved.	Planners and policy makers stop when time, money or patience run out.
Type of solution	Unambiguous, can be independently said to be true or false.	Ambiguous, more subjective judgments of “good” or “bad”.
Assessing solution	Impact of solution can be assessed immediately.	Impacts measured over a long time scale, repercussions hard to measure.
Consequences of imperfect solutions	Consequences do not alter the problem.	Consequences change the problem, require new problem formulation.
All solutions cannot be considered	A finite list of alternatives exists.	New alternative solutions appear constantly. Choice of solution is a judgment.
Transferability of solutions	Fall into classes of problems for which methods of analysis and potential solutions exist.	May share some features with other problems but essentially unique.
Symptomatic of other problems	Can be treated in isolation.	Frequently connected to “higher” problems.
World-view determines explanations of discrepancies	When results of action are unclear the rules for explaining discrepancies are bounded.	Determination of an effect from actions can be disputed using arguments outside of scientific discourse.
Judging actions	Unforeseen consequences of actions treated as valid data for new hypothesis testing.	Consequences of actions “matter” to the public and are judged by citizens and powerful stakeholder groups.

Source: adapted from [8]

Analysis

Biofuels in this discussion refer to the conversion of plant biomass to a liquid fuel used in transportation. This includes 1st generation biofuels derived from the starch, sugar or oil content of agricultural grain and root crops including corn, wheat, sugarbeet, and sugarcane converted to ethanol through fermentation, and oilseeds such as rapeseed or soybeans converted through esterfication to biodiesel. It also includes future generation transport biofuels not currently produced on a commercial scale derived from the lignin (wood) and cellulose content of plants (e.g. non-food leaves and stalks), and potentially biofuels from algae.

A careful delineation between liquid transport biofuels and other forms of bioenergy is important to avoid attributing features of one type of biomass production chain to all biofuels. For example, biodiesel derived from rapeseed involves different supply chains, sectors and legal frameworks as does wood chips from forests used in district heating or biogas from municipal waste. The bioenergy sector includes an array of different feedstocks, supply chains and different final energy uses which complicates understanding and communication around biofuels [2, 16]. Defining the object at the heart of a problem is a key step in the planning process [8] and wicked problems resist even this fundamental step. This initial characteristic of the wicked problem formulation is where we begin the analysis.

#1 No clear formulation of the problem

From the outset the objective of biofuels support programs from governments in Europe and North America have been towards multiple goals. Three main objectives are frequently cited in government rationales; mitigating climate change, improving energy security and promoting rural development [17-20]. The construction of biofuels as a win-win proposition for this variety of problems is understandable given the political need for governments to appeal to broad constituencies. However, the breadth of such policy unavoidably forgoes an in-depth treatment of particular issues. The original problem has been poorly defined in the sense that biofuels have been presented as a solution to multiple complex challenges. While biofuels can provide many benefits, they are in no way an overall solution to these societal challenges.

As biofuels production has expanded, biofuels themselves have taken on the dimension of a problem. There has been a shift in stakeholder views of biofuels as a win-win solution to an issue demanding careful management and even calls for a complete “stop” until strong sustainability safeguards are enacted. This change has occurred in the media [6], among formerly supportive civil society organizations [21-22], in the academic literature especially that of the natural and environmental sciences [23-26] and in government appointed reviews [27]. The way in which biofuels shifted towards a planning and governance problem has been documented and analyzed by many authors and organizations [1-2, 5-6, 28-32]. The shift from solution to problem is emblematic of the foremost challenge that Rittel and Webber [8] describe for wicked problems. Essentially, when it comes to biofuels there is no universally agreed upon problem formulation, and no objective way to distinguish symptom from cause.

#2 No stopping rule

There is no final solution to wicked problems, no point at which the matter is settled. We suggest the experience of North American and European regulators dealing with calculations of GHG emissions from indirect land use change (ILUC) exemplifies this characteristic. The ILUC concept attempts to quantify the changes in land use and resulting loss of stored carbon that could occur with relocation of agricultural production to forest or grassland for biofuels. This goes beyond trying to account for direct conversion of previously uncultivated land to crops for biofuels production and refers to attempts to allocate indirect emissions resulting from predicted overall expansion of cultivated area around the globe. In the Energy

Independence and Security Act the US Congress specifically mandated the Environmental Protection Agency (EPA) to include consideration of indirect GHG emissions during rule-making. Upon completion of the Renewable Fuel Standard 2 (RFS2), the EPA indicated that, while it was required by law to reach a decision on ILUC in the RFS2 regulation, the solution to the ILUC question was incomplete. "*As scientific knowledge continues to evolve in this area, the life cycle assessments for a variety of pathways will continue to be enhanced...This new assessment could lead to new determinations of threshold compliance compared to those included in this rule*" [33: 6]. Rittel and Weber [8] suggest that wicked problems stop because of considerations outside the problem, rather than final solutions. In the case of RFS2 the rule had to be promulgated because planners ran out of time, not because a definitive answer was reached on ILUC effects.

The European experience is similar. The Renewable Energy Directive (RED), which sets out biofuels targets, gave the European Commission (EC) a deadline to review the ILUC issue and make recommendations. In late 2010, the EC issued its review which did little more than announce further study [34-35]. New modelling studies now completed have extended earlier findings [36-37] and, in doing so, identify a new focus: "*the real challenge is to promote better land use practices for agriculture widely*" [38: p 51]. It remains to be seen how the EC will incorporate these recent studies into biofuels policy, particularly the RED, and if there is patience and political will to extend towards new focus areas. Again there is no stopping rule. In the end, the EC efforts to quantify ILUC effects have been a prolonged affair with little sign of a definitive answer.

#3 Type of solution is ambiguous

Wicked problems do not have definitive solutions; instead solutions are ambiguous and are considered good or bad, not true or false. This aspect of the biofuels situation has changed over time. In the early 2000s biofuels were widely considered a win-win solution with little ambiguity. Indeed there was no need for solutions. Biofuels replaced fossil fuels and this was seen as an ample and sufficient reason for support. However, as concerns have mounted, various solutions have been proposed. Requirements for proof of minimal GHG savings were introduced into later versions of the US Renewable Fuel Standard and the EC Renewable Energy Directive. The EC also introduced "sustainability criteria" to avoid cultivation of biofuels on high conservation value land and set in legislation requirements to monitor impacts of biofuels on food security and land use rights [19].

Where there was once clarity now there is ambiguity regarding the best ways to develop biofuels. There is no one best solution, only different options. Which is better, the US rules that require biofuels to reduce GHG emissions by 20% or those of the EU which require 35% reduction but do not allocate an indirect land use emissions penalty? There is no definitive answer. It depends on who is doing the judging. Given the wide difference between actors such as Greenpeace, who judge biofuels worse than the fossil fuels they were designed to replace [4], and bioenergy industry associations like the World Bioenergy Association who envision biofuels meeting global energy demands [3], solutions will remain contested and ambiguous. We can expect intensified debate as the production and trade of biofuels continue to expand.

#4 Time required to assess solution extends indefinitely

Tame problems have solutions that can be assessed on the spot, while wicked problems require longer time periods to assess the effectiveness of solutions. As suggested, the issue of ILUC suggests that biofuels have shifted markedly to the wicked side of this characteristic. The ILUC concept attempts to account for the loss of stored carbon anticipated from the increased demand to farm more feedstock to produce biofuels [23, 25]. This can only be assessed by predictive modelling which in turn requires regular monitoring to assess if land use has changed as predicted. Furthermore as Rittel and Weber [8] suggest, as the time horizon for assessment expands, the scope of consequences to be assessed also expands. One logical response to the incorporation of ILUC in biofuels assessments is to expand the boundary of petroleum assessments as well. A provocative suggestion has been to include even the indirect military GHG emissions produced to secure oil supplies [39]. In theory, an unlimited amount of time is needed to fully assess indirect GHG emissions.

Assessing biofuels is further complicated by the ever-evolving nature of the industry. Take for example the new considerations that will be part of any scaling up of algae biofuels technology. Early predictions are that water management issues will be central and include some novel challenges such as monitoring municipal wastewater streams for algae pathogens [40-41]. The arrangement and lay-out of algae production infrastructure is not yet known but questions are being raised about public support and local community acceptance of production sites [41]. With the wide array of feedstocks and technological pathways possible for biofuels there will an ongoing need for assessment on an increasingly wider set of considerations.

#5 Consequences of imperfect solution

Attempts to solve wicked problems change the nature of the problem, they leave "traces" and new problems appear. Again the biofuels example shares this feature. As biofuels production has expanded to solve one environmental problem of reducing GHG emissions from transport fuels, several new problems have began to appear. Initially these remained more or less contained within predictable parameters, for instance there were complaints from EU Member States that GHG reductions through biofuels use were marginal and unsuitable costly methods to combat climate change leading to gaps in Member States implementation of EU biofuels targets [42]. However, further problems emerged: we learned that the replacement of gasoline with E85 (85% ethanol, 15% petrol) is anticipated to increase ozone emissions leading to a rise in ozone related hospitalizations and mortality in the US [43]; that production of biodiesel from palm oil is likely to exacerbate loss of biodiversity as palm oil agriculture is known to replace forests and decrease biodiversity [44]; and that biofuels contributed to the spike in grain prices during the 2008 food crisis. Although it should be stressed that there is no consensus on the last point; according to a recent review of twelve analyses biofuels may have accounted anywhere from a relatively modest impact of 4% to a much more significant 75% of the rise in corn, wheat and rice prices [45].

Thus, while biofuels appeared to be a solution to the problem of GHG emissions, the solution is short-lived. As new issues emerge they complicate efforts. Any one of the issues mentioned above changes the context of planning efforts for biofuels and introduces new problems which require new solutions. To take one example, partly in response to concerns with deforestation associated with palm oil, the EC designed specific sustainability criteria for biofuels producers [19, 46]. To ease reporting requirements, officials accredited seven different certification schemes [46]. The area of sustainability criteria and international trade is particularly problematic for biofuels as the schemes applied to biofuels producers need to also ensure that the administrative burden and economic costs do not become a barrier to the production and trade of biofuels [47]. At the same time, there are also some people and organisations that simply do not believe such sustainability schemes can work, and so they do not see a future for any biofuels [7, 48].

#6 All solutions cannot be considered

When problems are wicked they can have any number of solutions. There is no list of alternatives that planners can rely on to be sure all solutions have been assessed or attempted. We argue that the significant literature distinguishing between "good" and "bad" biofuels [16, 21, 26, 49] are evidence of this characteristic. Prescriptions to avoid problematic side effects vary, some observers emphasize a need for less intensive agricultural practices to grow feedstock [21], others push for the integration of biofuels with broader policies for transport including high efficiency vehicles [21, 49], a few emphasize nurturing public perception of biofuels and promoting "bio-literacy" [16], and many favour accelerated development of cellulosic technology to make biofuels from residues [21, 27, 49].

These solutions are all plausible and no single one will objectively ensure "good" biofuels and prevent the development of "bad" biofuels. They are all permissible. The wicked aspect is that planners have no finite list of solutions. If the solution fails, is it because of a failure in implementation or because of a failure to identify the appropriate alternative solutions in the first place? As Rittel and Webber [8] note "anything goes" and it is more a matter of trust and credibility between actors as to what solutions to attempt, and if the attempted remedies help to resolve problems, make them worse or fall somewhere in between these positions.

#7 Transferability of solutions

Wicked problems are distinguished from tame ones by their uniqueness. They do not fall into a class of problems for which lessons on previous solutions can be easily transferred. Biofuels conceivably fall into three increasingly narrow categories, including: energy; renewable energy; and bioenergy. If this wicked characteristic is true for biofuels we should not be able to identify any unique feature of overriding importance for biofuels within these classes. From the broad perspective of energy, biofuels are distinct from other energy carriers like fossil fuels because of their origin in renewable biomass. This is a crucial and unique feature of biofuels.

If we move to the narrower classification of renewable energy, biofuels share a renewable resource quality with other sources such as wind, solar and water, but these sources can only be used to power vehicles if first converted to electricity or used to create hydrogen. Again this is a feature of overriding importance as biofuels can be stored and used when needed and they are compatible with the vast majority of vehicles in use today with internal combustion engines [50]. Finally, for the narrowest classification, biofuels share many features with other forms of energy based on biomass but their origin in agricultural crops is a distinct difference. This is viewed by some observers [26, 49] as a feature of "bad" biofuels. If future generation biofuels from straw and wood become commercialized, then the similarities between biofuels and biomass used for heat and electricity production will become closer. Until that point, biofuels remain unique, and therefore wicked.

#8 Symptoms of other problems

Rittel and Weber [8] suggest there is no natural level to a wicked problem. They can always be formulated as a symptom or a solution to another problem. Biofuels are connected to other problems by their origin as an “ill-defined” solution. As pointed out previously, biofuels are an attempt to mitigate climate change, improve energy security and contribute to rural economic development and as such are symptomatic of these problems. Yet the debates over biofuels suggest additional connections to further high level problems including land use competition, energy and chemical intensive agriculture [24] and a distrust of the public towards promises of technological fixes [5].

Recent developments by the EU to rely on sustainability certification standards [51] designed by non-state actors have been described as emblematic of broad shifts in environmental governance. In this context, biofuels connect to very deep challenges of democratic arrangements and the accountability of novel rule-setting bodies [28]. Thus from a variety of angles, biofuels appear connected to a wide array of problems and they can be approached from any one of these positions. No entry point is definitively correct and the way forward depends on which problem is prioritized, and therefore political questions of who is doing the prioritizing are very important.

#9 World-views of discrepancies

When problems are wicked, the types of knowledge used to explain discrepancies between intended and actual outcomes expand beyond scientific discourse. Hypotheses are defended using explanations that conform more to worldviews than to strictly empirical interpretations. This feature is most clearly present in dire criticisms that biofuels caused the 2008 food crisis. These claims were made with much rhetoric despite mixed evidence [7, 21, 45]. A more subtle example of how biofuels judgments rely on values as much as – if not more than – strictly empirical facts, can be found in the following example. A high-profile group of scientists wrote in *Science* in 2009 without irony: “*The recent biofuels policy dialogue in the*

United States is troubling. It has become increasingly polarized, and political influence seems to be trumping science. The best available science, continually updated, should be used to evaluate the extent to which various biofuels achieve their multiple objectives and policy should reward achievement....those who have invested in first-generation biofuels should have a viable path forward." [26]

The last statement is entirely normative and based on (culturally-contingent, subjective) views that it is only fair to allow early investors to recoup their investment. While this position may have wide support it has to be recognized for what it is in reality. A position based on norms and moral values not an argument arrived at using the scientific method. Several recent studies have explored how the world-views of key actors influence judgments of biofuels. Senger *et. al.* [6] measure trends in media discourses and Hansen [52] links different biofuels discourses to disciplinary differences between biochemical scientists and life cycle assessment scientists. It is very important that the biofuels community remains alert to these issues.

#10 How actions are judged

Failed attempts to solve tame problems are treated as hypotheses which generate valid data for future attempts. Few actors outside of the problem solvers themselves are aware of failed attempts. For wicked problems there is no such "immunity". Biofuels fall into the latter category as the consequences of efforts to develop biofuels "matter" to a wider audience and thus challenge the role of biofuel experts as the only appropriate arbiters of successful or unsuccessful actions. When *Rolling Stone* magazine called ethanol *"a scam"* and *"one of America's biggest boondoggles"* in 2007 [53] it both created and confirmed a wider audience for biofuels developments. Today, it is not uncommon for national media to ascribe the real motivation for US biofuels policies as the pandering of presidential candidates to the first-in-the-nation voters from corn rich Iowa [54].

A different example – and one that is less driven by the need for eye-catching headlines – may be the raising of biofuels to the status of an ethical issue. In the EU, the Nuffield Council on Bioethics proposed six moral values to guide biofuels development, including human rights and solidarity and the common good [55]. The attention from the Nuffield Council on Bioethics on biofuels shows that the sector is not just being scrutinized from environmental and socio-economic perspectives but also from an ethical viewpoint. When the consequences of biofuels are judged by core ethical values it is a good indication that efforts to develop biofuels are attracting a very wide audience.

Discussion

We have presented arguments that the biofuels case exhibits all of the wicked problem characteristics. We recognize that it is difficult to disentangle where biofuels end as a solution to other major problems such as climate change and where they start to take on the characteristics of their own unique problem. We suggest that the range of side effects incurred during biofuels development makes it correct to consider them as a unique problem. As we have shown, their side effects include not only unforeseen indirect GHG emissions, but also questions of health effects, impacts on international grain markets and food security, habitat loss, and ethical concerns over small landholder rights. In other words they are not only connected to one single higher problem or one single lower problem. Furthermore, Rittel and Webber [8] tell us that this very characteristic of confusion between a solution and a problem, between a symptom and a cause is a key characteristic of a wicked problems, and connections to other higher and lower order problems is another feature. Therefore we propose that there is enough affinity between the ten characteristics and the biofuels case that it could be instructive to start to look more deeply at lessons already learned for planning for other types of wicked problems.

Planning is a broad term and the term “planners” encapsulates a wide range of future-oriented actors including project managers, both corporate and public, policy analysts working for governments or civil society groups, and regional, state and federal level government agency planners and in Europe, the EU and its various bodies [56]. In the biofuels case we consider planners as those working in government, industry, and civil society engaged in designing regulation and incentive schemes but also those making business decisions on production facilities and choosing directions for research and innovation. All of these are future-oriented actors planning around biofuels. There are obvious differences in the roles of such individuals and the aspect of biofuels development that they deal with, but they are all affected by biofuels turning towards a wicked problem. Consider for example, biofuels producers entering into negotiation with NGOs and farmers under schemes such as the Roundtable on Sustainable Biofuels [57]. Such an activity would not have been anticipated five or ten years ago.

In reaching the status of a wicked problem biofuels are at a point whereby political questions of “what ought to be” are more important than scientific questions of “what is”. The policy studies literature provides some tools for understanding how to approach this type of situation. Most important is to use differentiated strategies for different parts of the problem. When the means for obtaining a solution are clear and the goal known then conventional scientific procedures are appropriate to follow. For example, further studies of ozone emissions from burning E85 (85% ethanol, 15% petrol) fuel have refined earlier findings [43] and suggest that the health effects of emissions are greatest at colder temperatures [58]. Through a traditional scientific process, planners now have some information to consider a set of options for this sub-problem, for example implementing seasonal or cold region rules for E85 use. This situation of broad agreement on the goal to be reached and on the processes to reach that goal corresponds to the upper left-hand box of the matrix developed by Christenson [59] (see Figure 1), which suggests a planning strategy of "programming" or what Funtowicz and Ravetz [13] call "applied science".

Figure 1 – Strategies for planning problems

Process to reach goal (means)		Goal (ends)	
		Agreed	**Not agreed (post-normal science conditions)**
	Known	Programming Compare options and optimize solution.	Bargaining Identify and accommodate multiple interests. Extended peer review.
	Unknown	Experimentation Trial and error. Build database of options.	Chaos Discover or create order. Look to different knowledge types.

Source: adapted from [59]

Other aspects of the biofuels problem have an agreed upon goal but unknown means to get there, which is depicted in the lower left-hand box of the matrix. These are more amenable to experimentation strategies. For example, many agree that biofuels should reduce GHG emissions compared to conventional fuel options; there is even agreement that Life Cycle Analysis (LCA) is the appropriate method to make measurements [19, 33, 55]. However, there is disagreement over methodology, over how best to calculate indirect land use emissions [34, 55] and the best way to attribute agricultural emissions [60]. A relevant strategy in this case is to facilitate sharing of methods and LCA calculation factors, which is done by the National Renewable Energy Laboratory in the US through the sharing and publication of the the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed at the Argonne National Laboratory [61]. This GREET model builds a database of information that can validate other models and contribute to more robust and trusted LCA outputs. We would also place support for research and testing oriented towards technical and yield advances in algae and other advanced biofuels in this quadrant. However, we suggest that even if advanced biofuels become technically feasible, planners should avoid automatically instituting production incentives or setting mandates without involving a broader public. The social feasibility of advanced biofuels is no longer automatic; implementation of future generation biofuels is firmly within the right-hand side of the matrix where goals are not agreed upon.

The right-hand side of the matrix is the realm of politics and where wicked problems and post-normal science meet or perhaps collide. The post-normal science concept developed in the early 1990s [13, 62] embraces a role for politics in science and it is therefore a useful, if somewhat “fuzzy”, source of ideas for ways forward. Its emphasis is on dialogue over proof, where evidence derived from common-sense knowledge is equally required to properly inform decisions about political problems. Scientific material is not to be treated as incontrovertible fact, it has a context (e.g. it may or may not be applicable to the question at hand, or it may rest on uncertain assumptions) which is open to critique [9, 14]. A central goal of post-normal science is to extend the peer review role to non-scientists and by doing so insert a quality check on scientific findings. It is said that only by enrolling cultural and moral knowledge can evidence of a high enough quality to address wicked problems be found. In contrast to normal science, the emphasis is more on establishing relevant information for uncertain situations than on falsifying hypotheses [62]. Post normal science is quite an abstract concept and its application is usually expressed in ideas of expanding citizen participation in defining policy directions and research goals [62] often under the umbrella of activities such as alternative future scenario workshops [12, 63].

The notion that scientific findings can be trumped by political process or social values is, of course, well-known and considered appropriate in many contexts. The upper right-hand box of the matrix corresponds to common planning dilemmas, for example when city planners face conflicting goals such as conserving green space or zoning land for residential development. There are often agreed upon mechanisms to achieve each goal but disagreement on which goal to follow. Bargaining between interest groups or between competing planners is then used to select the goal. This process is susceptible to co-option by powerful interests [64] and efforts should be taken to recognize the voice of the less powerful [56, 65]. The concepts of collaborative planning [66] and deliberation between a full range of stakeholders are important here [67-68]. Some suggest legitimacy can only be achieved when planners give up their decision-making power, by-pass interest groups and participate with citizens to define and solve problems [67]. Examples of how this can work is the use of deliberative polling (polls combined with facilitated workshops) to guide energy choices [69-70]. A key part of this is providing training to citizens to grasp technical complexities. In the deliberative polling experience, enough fluency can be gained in a workshop [69]. There may be other ways to communicate and nurture “bio-literacy” to facilitate deliberation over biofuels issues among the general public [16]. A key challenge is implementing such efforts on a wide scale and in convincing decision-makers of the value of non-expert knowledge. The lower right-hand box of the matrix shows situations when neither ends nor means are agreed upon. At this stage – even more than in the previous stage of bargaining – values become more important than facts in determining appropriate solutions. The challenge is how to incorporate insights into the social world of norms and values (what some social theorists define as “practical” knowledge as distinct from scientific “theoretical” knowledge [71-72]) to biofuels governance. This could involve efforts on two fronts. First, an expanded role for research from the interpretive social sciences and from the humanities, examples include: studies using methods of discourse analysis which have helped reveal how and why different groups of people choose different representations of biofuels [52], how traditional scientific framing of issues can close down biofuels debates [34], and how imagined bio-economy futures empower certain policies to the exclusion of alternatives [73]. Second, by providing venues for “extended peer review” of biofuels technical knowledge. The multi-stakeholder biofuels certification schemes, like the Roundtable on Sustainable Biofuels [57], are one example.

In summary, our perspective on the lessons from wicked problems in other sectors is that differentiated planning strategies are required. Some of the challenges that have emerged for transport biofuels can continue to be tackled by the traditional separation between scientific knowledge production and politics whereby scientists and engineers provide better and better models or equipment and it is left to planners to devise the most effective means of implementing that knowledge. The challenge of minimizing negative effects of tailpipe emissions may be one example of such a traditional challenge where planning strategies of “programming” and “experimentation” will be effective. However for many biofuels challenges we suggest a strict separation between science and politics is untenable. For challenges such as ILUC, or appropriate governance of trade in biofuels there is simply not enough certainty in any scientific knowledge produced on these issues to warrant a separation between scientists, planners and the public. Negotiation and bargaining are one strategy to follow. For pragmatic as well as idealistic reasons this should be done in an as equitable and coercion-free atmosphere as possible. Rittel and Webber [8] and Sherman and Peterson [68] tell us that wicked problems are never permanently solved, instead solutions must be continually posed to meet changing conditions. This is also true of biofuels because their impacts will continue to change affected by a diversity of drivers and constraints. There will be no permanent solution because the types of issues that biofuels touch upon such as resource allocation, climate change, and globalization are social ones and they are endemic. Finally, there needs to be a concerted planning effort by the biofuels community to explore the values that underpin support and opposition keeping in mind different contexts and situations.

Conclusion

In this paper we have introduced some tools from the planning literature to diagnose some of the difficulties facing the expansion of biofuels. We label biofuels as a wicked problem because we suggest there is a need to recognize the complex social and political issues that surround what was once only considered a technical solution. We suggest the idea of differentiated planning strategies is important to future biofuels action and advocate for a wider role of the public in biofuels decision-making. The wicked problem concept reminds us not to expect permanent solutions. However, the wicked nature of a problem can be minimized by finding ways of assessing and incorporating social value arguments into decisions [68]. Post-normal approaches to science that enroll more perspectives and more knowledge types may be relevant to working through wicked problems. At the very least we need to recognize that when proponents of biofuels try to promote them it is not just about what “facts” they can present but also about broader visions and ideas. As a ready alternative to petroleum, we believe biofuels can be part of a sustainable future. However, this is not automatic and it is no longer a question of simply “getting the science right.” Rather, it is a question of how to accommodate conflicting values and uncertainty. These are difficult questions that require a willingness on the part of scientists, engineers and planners to share authority and establish fora for external peer review.

Future perspective:

Ultimately, the planning context for biofuels depends on forces which are difficult to predict. Progress on an international framework to reduce GHG emissions would change the context for the importance of biofuels GHG savings. Technological breakthroughs of future generation biofuels or of non-conventional sources of fossil fuels like shale gas or methyl hydrates will alter the energy security context. However, it is very likely that there will continue to be significant public and stakeholder scrutiny of biofuels developments in the near and medium term no matter the wider context [2, 74]. Minor setbacks in the commercialization of algae or cellulosic biofuels will be magnified. To some degree this could be remedied with efforts like deliberative polling of citizens by public authorities in candidate production sites. However, there is little indication that officials are pursuing this kind of "extended peer review" approach. Instead the efforts of the EC and the EPA in the US to commission ever more technical advice on the ILUC issue suggests that any future controversies will be managed by searching for traditional scientific advice instead of knowledge from post-normal science approaches.

The endorsement of non-state produced sustainability certification schemes by the EC is a significant development and may indicate that part of the future for biofuels can be predicted by referring to other examples of non-state rule making efforts. The case of forest certification may be instructive [75]. In forestry, certification schemes with strong support from NGOs competed with those initiated by industry and landowners throughout the late 1990s and early 2000s. The amount of forest products certified to the industry-backed schemes rose more rapidly, but the legitimacy of this certification was contested by NGOs who staged protests and lobbied major wood purchasers to commit to purchasing wood certified under their preferred scheme. Certification of biofuels could follow a similar path with a large proportion of biofuels certified, but mostly to schemes that NGOs find illegitimate. If this occurs the EC will be under pressure to reconsider its endorsement. An improbable outcome is that NGOs attempt to increase their leverage by working with biofuels purchasers (petrol and diesel companies with filling stations selling fuels blended with biofuels) as was done with wood purchasers.

Finally, another possible biofuels future is one shaped by Brazil and tropical regions. Our analysis has been focused on the North American and European experience. The Brazilian experience has been different where sugarcane based ethanol makes up a majority of domestic fuel use and exports are rising [76-77]. High sugar content allowing for rapid fermentation to ethanol and favourable growing conditions mean ethanol production is more energy and GHG efficient than in the US or EU [76]. Furthermore, sugar is not a staple food and impacts on global grain prices are minimal. These natural advantages suggest the possibility of continued biofuels production in tropical regions of the world for growing domestic populations and exports. However, exports to the US and EU will likely be subject to continued trade barriers both explicit such as tariffs on Brazilian ethanol [77] and implicitly in the form of sustainability certification requirements. All of which underlined the wicked problem of biofuels.

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*of interest
** of significant interest

** Christensen, K – Provides a conceptual framework for identifying uncertainty in planning problems. Uncertainty can exist for goals and for the means with which to meet goals. Each combination of uncertainty suggests different strategies and types of planners.
* Fischer, F – Good mix of historical context of planning profession and of the practical and theoretical need for participatory research. Gives two examples of participatory research, including one where a community decides to host hazardous waste, and the other of citizens linking toxic wastes to leukemia.
** Funtowicz and Ravetz – Introduces concept of post-normal science and its relevance in situations where applied science and "consultancy" are insufficient. Many provocative observations, including that for post-normal problems there is an inversion of "facts" and "values" in importance.
* Govinda and Shrestha – Relatively recent review of transport biofuel developments from authors affiliated with the World Bank. Good section on studies of biofuels impact on food prices.
*Liska et al - A somewhat rhetorical argument against application of rules upon biofuels for indirect land use greenhouse gas emissions.
**Rittel and Webber – Classic paper originally describing the wicked problem concept. Describes ten characteristics of such problems. Suggests that all planning problems are wicked because of modern world differentiation of values accompanying differentiation of publics and planners, which requires better social theory than those based on aggregation of individual preferences.