Paper for SPRU 40th Anniversary Conference 11-13 Sept 2006 Brighton UK

Innovation for sustainability: The case of sustainable transportation

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Abstract

Global warming and energy security are the main drivers for innovation towards alternative and sustainable energy solutions. The prevailing notion is that eventually technological innovations will solve the problem. However, scenario studies point out that deep change processes in institutions, life styles, and values will be necessary in addition to technological innovations. Moreover, there are some persistent problems with technological innovation itself:

- In the case of energy for transportation, there is no consensus about which technologies to choose and how to select them. Picking winners is not a good idea, but keeping options open is neither. There seems to be a consensus that, in the long term, hydrogen fuel cells, battery electric vehicles, or biofuels are the only available sustainable options. It is not clear how and when to choose, depending on long-term cost-benefits and risk assessments, on public acceptance, and on the urgency.
- Technological innovations are mainly driven by large business interests and by large government programs. After many years of discussion, supply side policies still dominate demand-side approaches. Thinking from the perspective of sustainability is even less developed. Transportation is again a case here. From the perspective of sustainability, the automobile is a suboptimal solution to individual mobility needs.

In this paper we explore both theoretically and practically some alternative ways of thinking about how to connect technological innovation to sustainability. First of all, we think that small-scale experimentation including heterogeneous actors will help to generate deep learning processes, which are relevant for transitions to sustainability. In earlier papers we have coined the concept of BSTEs, "Bounded Socio-Technical Experiments" as situations in which deep learning could be generated and diffused into wider society.

Second, we think that visioning exercises with heterogeneous stakeholders will help to create shared future visions for sustainable societies that are powerful enough to guide BSTE processes, and eventually could influence policy making aimed at the long term. In the Dutch Sustainable Technological Development program in the 1990s, and in the SusHouse project we have showed the viability of such an approach. Third, we think that back-casting from future visions, in combination with BSTEs, could generate roadmaps for technology development and policy development that will guide and direct individual innovation efforts. In the Netherlands backcasting is currently being investigated as to its effectiveness in generating long-term changes.

As examples we will describe two cases: hydrogen fuel cells for transportation, and the Boston Scenarios Project. In the first case, we lay out the options and uncertainties, and explore the possibilities for a broad societal debate in addition to small-scale experiments, in order to develop a clear broadly-endorsed solution direction. In the latter project, a combination of visioning, BSTEs, and backcasting is being developed in order to generate "deep change" alternatives for the "Business As Usual" scenario for the Boston area. For transportation, "Deep Change" goes beyond fuel cell solutions and

includes land-use planning, rezoning, education, and experimentation and learning in multi-stakeholder processes, as well as walking, biking, and public transit

The role of governments in each of these examples remains contested. Ideally, governments should act as trustees for future generations and for fostering sustainability, and provide strong guidance for policies. In the present situation of short-termism, at least in the USA, civil society and forward-looking entrepreneurs may have to take the lead to help governments to redefine their roles.

For the development of innovation theories, the paper will reflect on how these approaches could fit in or stretch existing innovation theories.

1. Introduction: challenges for sustainable innovation

Technological innovation and diffusion play a central role in the pursuit of environmentally sustainable development, along with changes in consumption patterns. Often it is assumed that radical [Abernathy et al, 1985] or disruptive [Christensen, 1997] innovations are necessary for sustainable development.

There are however some environmental problems that are so complex that that technological innovation alone is unlikely to be able to address them successfully. The most debated is climate change by human-activity related CO2. The increasing global population and the increasing standards of living around the globe (for the poor a requirement for sustainability), as well as the development of new products and services by technological innovations, cause CO2 emissions to increase to levels that are highly unsustainable, especially for climate stabilization.

In addition to climate change issues, increasing global energy consumption causes threats to energy security. We are far from reaching a consensus on how to address these issues in a globally integrated and sustainable way. In the 1990s most scholars on sustainable innovation assumed that dematerialization combined with energy efficiency could help to decouple energy consumption from economic growth. Indeed some progress has been made: especially industries using Life Cycle Assessment and Life Cycle Costing focused on dematerialization of products, reducing packaging, and reducing energy intensity of appliances. However, increase of personal consumption following more wealthy life styles, rebound effects, new electric appliances especially in ICT, and the increasing numbers of consumers world-wide have more than annihilated this progress

The most debated technological options are energy conservation and energy efficiency, renewable energy, nuclear energy, biomass, and carbon capture and storage. Energy conservation and efficiency efforts draw on such technologies as insulation of houses, heat exchangers, heat and cold storage, heat pumps, cogeneration and more efficient internal combustion motors, as well as life-style changes. Renewable energy is widely accepted as the solution of the future, however is hampered by high costs, NIMBY battles especially on wind energy, and lack of incentives to innovate and to reach the mass markets. Nuclear energy is back on the agenda, but is still highly contested because of lack of long-term solutions for radioactive waste storage. Biomass and biofuels are promising, and embraced by the EU and by the US government, but at this stage they still take a lot of energy to produce, and require large tracks of land.

Carbon capture and storage (CCS) is a newly emerging technology that promises to store CO2 deeply underground for a long time, but may face in the future similar challenges for public acceptance as nuclear and wind energy (NIMBY and public trust) [Stephens et al, 2005].

In the case of personal transportation the issues of energy generation take on additional dimensions because of the need for on-board storage and possibly on-board generation. Among the most promising technologies is electric propulsion either by batteries or by fuel cells. Battery-electric vehicles (BEVs) have failed on the market several times [Van den Hoed et al, 2006; Orsato. 2006], but improvements in battery technology and other forms of energy storage (flywheels, compressed air) hold some hope. Of course electric traction requires the sustainable supply of large amounts of electricity, which brings us back to the problems of the potential of renewables. Fuels cells could be another solution; however hydrogen in PEMC is highly discussed because of the high inefficiencies of producing and using hydrogen [Weiss et al, 2000, 2003; Vergragt 2006], and the possibility of other fuels for fuel cells (methanol) or other types of fuel cells (for example, solid oxide, SOFC).

Because of the systemic character of many of the challenges and of the potential solutions it is not enough to address single technological innovations and diffusions. Instead, an entire complex of technologies and their interlinkages needs to be addressed. What makes things worse is that the recent trend toward deregulation has made many governments less able to influence technological innovations than before. Additionally, a large-scale and long-term transition such as this involves numerous actors. Many of them have a stake in the existing situation and in current technologies, which raises the question of technological and institutional lock-ins.

One way out of this vicious cycle is to infuse the present socio-technical system of individual mobility with a greater capacity to reframe problems, to synthesize the accumulated cross-disciplinary and cross-institutional knowledge, and to set and articulate alternative policies and technology trajectories. In part 2 of this paper we argue that a combination of visioning, backcasting and small-scale experimentation are promising approaches to purse these objectives. Drawing on the theories of learning we make a case that these approaches facilitate systemic change by way of increasing higher order learning on a scale of individuals, groups, and the society. Part 3 discusses these ideas in more detail, using the case of hydrogen fuel cells for transportation. Part 4 considers the case of transportation through in the context of a sustainable city, using Boston as an example. In part 5 we build on the two cases to discuss the importance of the new approaches for innovation studies in general and for innovation for sustainability in particular.

2. Visioning, backcasting, small-scale experimentation, and higher order learning

One of the turning points in framing the prominent role of technological innovation in the sustainability debate was the shift, during the 1990s, from local and short-term thinking to global and long-term time horizons. Related to that was the emergence of the concept of “Factor 20”. Drawing on the IPAT equation [Ehrlich et al, 1971], the Dutch Sustainable Technological Development (STD) program introduced the “factor 20” challenge, meaning that for each unit of need fulfillment (viz. transportation of 1 person 1 km), the intensity of energy and materials consumption would need to be reduced twenty-fold [Vergragt et al, 1993, 1994; Weaver et al, 2000]. The STD program recognized that the existing environmental policies, focused on end-of pipe pollution prevention and process and product innovation, were inadequate for the task. Instead, system innovation would be necessary, which would entail not only technological innovations, but also changes in "culture" and "structure", meaning institutions, life styles, and consumption patterns. Such structural changes would also mean changes in the economic and political structures.

The Dutch STD program introduced three innovative ideas for generating a momentum and hopefully a trajectory towards the needed system innovation: visioning, back-casting, and illustrative processes. 'Visioning' is a development of a future vision of sustainable function fulfillment that would be shared by all relevant stakeholders in the supply and demand chain, from production to consumption. For this, workshops were organized in which representatives of the supply chain and consumers brainstormed about "factor 20" solutions. In the STD program the emphasis was still on the development of radical or disruptive technologies. Later on, in the EU-funded "SusHouse" project the emphasis shifted toward changing consumption patterns; the "Sustainable Household" was a reference point and as a place where "sustainable consumption" would be located [Vergragt et al, 2001; Green et al, 2002].

When used appropriately, visions can be powerful devices for orienting and structuring actions and behaviors. They have the power to inspire social actors to investigate and test alternatives-- from technology to behaviour to culture and institutions. Shared visions may unify competing or warring interests by creating a shared framing of a situation. According to Grin and Grunwald "*...one way to shape socio-technological systems is through the visions that guide their development… the assumption is that these visions exist already in most societal sectors, that these visions tend to reproduce the ways in which these sectors have developed hitherto, and that a critical discussion of these visions is a prerequisite for changing the course of development"* [Grin et al, 2000].

Visioning can create trend-breaching scenarios for *desirable* (in contrast to *possible*) futures. For instance, sustainability visions of the future might imply breeches of trend from the present developments. These breaches may be technological (radical or disruptive innovations), but more often they are social and cultural (shifts in values from individualistic to communal, from increasing wealth to increasing well-being, from owning to sharing). In the SusHouse project (Vergragt et al, 2001, Green et al. 2002) creativity workshops with stakeholders have been used to create the elements of normative future visions that depart markedly from presently dominant values in society. In a related approach, Berkhout et al (2002) developed socio-economic scenarios in relation to climate change and conceptualized them as "learning machines" meaning "…the capacity to bind together the mental maps of diverse communities and to enable them to imagine alternative futures collaboratively."

"Backcasting" is a process whereby the construction of a future vision or normative scenario is followed by looking back in time and creating a strategy or action plan for proceeding from the present towards that desired future [Vergragt, 2005, Quist et al, 2006]. The origin of backcasting goes back to Amory Lovins, who proposed 'energy backcasting' as an alternative planning technique for electricity supply and demand in the 1970s [Robinson, 1982, Anderson, 2001]. A similar approach has been applied in the "Great Transition" scenario by the Tellus Institute. Based on the earlier work by the Global Scenario Group (GSG), Raskin et al. [2003] visualized a "Great Transition" towards a global sustainable society towards the end of the 21st century, and a possible pathway how to reach that. Earlier scenario studies had indicated that most trend-following scenarios would lead to unsustainable situations like "Fortress World" or "Barbarization." In contrast to the STD program, Tellus Institute sees the dynamics of change coming from civil society rather than from technological innovation or from government policies.

"Illustrative processes" were examples of socio-technical innovations that have the potential to achieve a factor 20 if diffused on a large scale: for instance, Novel Protein Foods was based on the idea that meat could be produced outside an animal with an enormous environmental efficiency [Weaver et al, 2000]. This would entail a massive restructuring of the food, and especially the meat, industry. Obviously cultural and structural factors would play an great role here; restructuring of the food industry and rethinking the need for "meat" by consumers are big challenges.

The STD program was ambiguous about the role of illustrative processes. On the one hand, they were seen as loci for experimentation and learning; on the other hand they were seen as the first steps in a possible transition to a final state. There is also a tension between achieving factor 20 by deep cultural, structural, and technological changes (or system innovations or transitions), and carrying them out by presently powerful economic actors with a deep stake in the present culture and structure. The same tensions can be seen in the present "transition management" thinking with respect to small-scale initiatives in niches [Rotmans et al, 2001, Kemp et al, 2005].

Related to illustrative processes is the concept of "Bounded Socio-Technical Experiment" (BSTE), which we introduced in recent years [Brown et al, 2003, 2004, 2006]. The key role of such experiments is to induce higher order learning among the participants, with the idea that such learning is a fundamental precondition for achieving deep changes in technology, culture, and institutions. The term BSTE denotes "….an attempt to introduce a new technology or service on a scale bounded in space and time….. it is a collective endeavor, carried out by a coalition of diverse participants. There is a cognitive component to BSTE in that at least some of the participants, and definitively the analyst, explicitly recognize the effort to be an *experiment*, in which learning by doing, trying out new strategies and new technological solutions, and continuous course correction, are standard features".

A BSTE is driven by a long-term and large-scale vision of advancing the society's sustainability agenda. Its goal is to try out innovative approaches for solving larger societal problems of unsustainable technologies and services. It can provide an opportunity for testing the feasibility of a new technology or service before it is ready to enter the open market. A successful experiment creates a functioning, socially embedded new configuration of technology or service, which serves as a starting point for diffusion. A less obvious, but crucially important, measure of its success is the occurrence of higher order learning among its participants, even in the absence of wide replication.

We built on the work of Grin and van de Graaf [1996a,b] to conceptualize learning processes in BSTEs. These authors applied Fischer's [1995] and Schön et al's [1983, 1994] framework of multilevel discourse to examine the learning processes occurring during constructive (or interactive) technology assessment. The participants in BSTE bring with them diverse perspectives and competencies, which in turn affect the meaning they attach to the project at hand and the ways in which they seek to contribute to the project and its outcome. We group these differences into four levels (closely following Grin and Van de Graaf [1996 a,b]):

1. Problem solving according to pre-determined objectives;
2. Problem definition with regard to the particular technology-societal problem coupling;
3. Dominant interpretive frames
4. Worldview

Worldview denotes deeply held values with regard to the preferred social order, including such issues as justice, fairness, equality, freedom, and private versus public good. Discourse at this level rarely occurs, is unlikely to produce changes, and is most dangerous for a collaborative project. By interpretive frame we mean the approaches to making sense of observations and to identifying the most salient characteristics of a particular situation. It is strongly linked to institutional and professional affiliations of its holder, his/her self-interest, as well as the worldview. Problem definition denotes specifying the task at hand or problem to be solved. Participants do so by examining the features of a particular situation through the lens of their respective interpretive frames and worldviews. Problem solving entails applying tools that the participant seems fit for addressing a previously defined problem. The discourse at this level proceeds primarily among members of the same profession or community of practice. This is first order learning.

The most intense interactions occur in BSTEs on the second and third levels. This is where the differences in problem definition, motivations for engaging in the project, individual interests and organizational missions, and perspectives on the particular technology become most clearly exposed and are most likely to confront each other. Generally, changes in problem definition are more likely than changes in interpretive frames. This is higher order learning.

Previously, we examined the cases of technological innovation in personal mobility [Brown et al, 2003, 2004] and in high performance building design through the lens of BSTE [Brown et al, 2006], focusing on mapping the learning processes among the participants. We also highlighted the potential contribution of this type of learning to changing professional norms and standards, and to catalyze diffusions of learning on a scale of a society. The latter needs further empirical study.

3. Hydrogen fuel cells for transportation

No shared future vision of sustainable transportation has yet emerged. Those authors who focus on the technological side of the equation agree that car propulsion of the future would be either by hydrogen fuel cells, batteries, biofuel, or a combination of those. Others claim that life style changes, and less dependence on individual car-based mobility, are necessary.

In the recent years some writers of popular science promoted the visions of a “hydrogen society” [Hoffman, 2000, Rifkin, 2002]. Bush has adapted this vision, and endorses research in hydrogen fuel cells, both in the public and private sectors [DOE 2992, 2003, 2004]. Others have criticized this vision as hype [Romm, 2006], as summarized in a recent paper by one of us [Vergragt, 2006]. There are other visions of a hydrogen society and research into pathways how to get there [Eames et al 2005, 2006].

Although a shared vision on a future sustainable transportation system has not emerged so far, there has been a lot of learning among stakeholders concerning the hydrogen fuel cell option for car transportation. Some of the issues are summed up below [Vergragt, 2006]:

-Hydrogen is not a 'source of energy' but not more or less than a carrier for storage and transport of energy

-Sustainable hydrogen needs to be generated by means of renewables or by 'clean fossil' fuels with carbon capture and storage (CCS); this may become the key technology to generate sustainable hydrogen for transportation. [Stephens et al, 2005]

-Not enough renewables may be available, and a competition with food production is an issue.

-The use of renewable energy to replace coal in power plants reduces CO2 emissions with a factor 2-3 more than by generating hydrogen for transportation. [Green et al, 2006; Ramesohl et al, 2006]

-For the short term, hydrogen for transportation thus is not a sustainable option. It may be for the long term (beyond 50-100 years) [Turton 2006, Bailie et al, 2006]

-Many technological innovations are necessary to provide hydrogen at competitive levels and for enough radius for car transportation

-According to Tellus Institute, energy efficiency and conservation are better options than hydrogen to achieve sustainability [Bailie et al, 2006]

-For personal transport, other options than the car are available

In sum, there has been considerable higher order learning around hydrogen. In order to diffuse this learning, a stakeholder dialogue may be helpful [Vergragt, 2006].

4. Planning for a sustainable city: the case of Boston

In a project supported by the U.S. EPA National Center for Environmental Research (2005-2007) Tellus Institute has been developing scenarios aimed at reaching sustainability goals for the greater Boston area by 2050 [Vergragt et al, 2006; www.bostonscenarios.org]. They have developed three sets of scenarios: 1) Business As Usual, without great surprises; 2) Policy Reform—with credible policy incentives for the short term); and 3) Deep Change—which, in addition to changes in technology and policy, assumes changes in behavior, lifestyles, and culture to address the deep shifts required to achieve a sustainable future that recognizes the Boston region's global responsibilities.

These scenarios comprise both a vision and a pathway for getting there. They have qualitative and quantitative elements. First, they develop narratives that describe these three alternative futures in terms of environmental, economic, and social drivers.

From these narratives, indicators are derived representing the key issues of concern. The project is using a computer-based tool called *PoleStar* to develop the quantitative scenarios. The *PoleStar* system is a flexible and easy-to-use decision support tool for sustainability studies at the local, regional, national, or global levels. A broad range of issues and sectors are integrated in the scenarios including demographics, employment and income, economic activity, industry, land use, transportation, water quantity and quality, air quality, solid waste, energy production and use, agriculture, etc.

Tellus expects to find that under both the 'Business As Usual' and 'Policy Reform' scenarios, the region's activities are not sustainable from a global perspective. Such scenarios are likely to show resource depletion, environmental degradation, and failure to live within a fair CO_2 budget or ecological footprint. Thus, the 'Deep Change' scenario will reflect a deeper commitment to meeting the region's global responsibilities and a preventative approach to environmental degradation and climate change. This will be constructed as a *backcast* from a desired future in 2050, identifying plausible development pathways for getting there, including the choices and actions for shaping a sustainable future. Apart from the "push" factors, exemplified by the threats of global warming and sea level rise, there will also be "pull" factors incorporated in the scenarios, which may make them attractive for future citizens, like more livable communities, the absence or minimization of sprawl, and an overall improved quality of life (as indicated by greater available leisure time, for instance).

Vision for Sustainable Greater Boston 2050

Transportation and Land Use

In the year 2050, the Boston metropolitan region has become a leading cultural and economic capital, famous for its environmental leadership. New land-use and transport practices are the great hallmarks of this new beacon of sustainability. Consistent with the MA Climate Action Plan and the New England Governors and Eastern Canadian Premiers Climate Action Plan, a reduction of GHG emissions from transportation in the region have been reduced by up to 80% since 2000.

Citizens are predominantly living and working near public transportation hubs. Public transportation is attractive because of high speed and frequency, high comfort, and convenient payment. This has reversed the decline in transit use the region experienced in the first few years of the century. Public transportation use is now routinely encouraged by employers who offer free or reduced cost transit passes as a benefit, and a high fraction of offices and workplaces being situated near transportation hubs. Easy access to transit stations is provided by an extensive MBTA[1] car-sharing program, as well as pick-up shuttle services using electric vehicles, underground parking spaces near stations, and high quality provisions for bicycle storage.

Individual car use has decreased as alternative public and private transportation options have become so convenient. Transit includes a number of modes: "bus rapid transit," rail, light rail, car-sharing, taxis, and ferry services. Walking, cycling, shared taxis, and high-speed transit have become easy, attractive, quick, comfortable, and less expensive than driving and parking, especially in Boston proper and the inner core communities. All public fleets and most private cars are hybrids or run on hydrogen that is produced from renewables or natural gas. Significant investments have been made in carbon sequestration projects within the region and outside it to reduce the net greenhouse gas emissions considerably.

[1] Metropolitan Bay Area Transportation

A large part of downtown Boston is closed for individual cars except certain categories (high-occupancy, all-electric or hydrogen vehicles; electric multi-occupancy taxis). In this area public transit is free; bicycle facilities are readily available (lanes, storing, zip-car-like renting system); and the long-needed rail link between North and South Stations is in place.

From an institutional perspective, public-private partnerships have realized innovative solutions by experimenting with new technologies. By including universities and technical institutes in research and development, new private high-tech enterprises developing innovative mobility solutions are thriving. Advanced information and communications technology (ICT) is widely used for road pricing, congestion pricing, fare payment, trip reservation, information and communication services, tele-working and tele-shopping, combining trips, and vehicles sharing. These organizations and businesses are an important component of a thriving regional economy. (source: www.bostonscenarios.org

The scenario development process includes stakeholder consultations and close coordination with an ongoing regional planning effort called MetroFuture, a project led by the Metropolitan Area Planning Council (MAPC), the Boston area's regional planning agency [MAPC 2004]. By linking the Tellus' scenario results with MetroFuture's broad stakeholder process —involving government, business, and civil society from around the region — other local and state policy initiatives, and grassroots citizens' efforts, they will receive broad consideration.

This project is an example of a visioning exercise, carried out mostly in-house by Tellus, but with regular consultations of stakeholders in the region by means of workshops and small consultation meetings. Backcasting is part of the agenda of this process. What still needs to be developed for this process is BSTEs in order to facilitate higher order learning. The closing of the inner city of Boston for IC vehicles could be an interesting experiment of this kind.

5. Conclusions and discussion

In this paper we have argued that higher order learning among stakeholders is a necessary condition for socio-technical system innovations. While there may be a broad based agreement on this notion among the "transition management" scholars, relatively little research thought has been given to how to facilitate such learning and how to study it. In this paper we advanced the idea that small-scale experiments (BSTE) facilitate higher order learning because of the sharing of a vision, varied participants, and the common focus on solving a technical problem. Visioning and backcasting are the necessary prerequisites to obtain a shared vision and the starting point for developing a roadmap for getting there. We also made reference to our empirical studies of such learning processes, based on a conceptual framework we proposed, building on the work of others.

The concepts of visioning, backcasting, experimentation and learning have obtained less attention in traditional innovation studies. Traditional innovation studies have focused more on individual innovations, on technological innovation in the firm, on sectors, or on national systems of innovation. Social-constructivist approaches have focused on actors and stakeholders and their interactions with each other and with the problem or the technology at hand. (Constructive) Technology Assessment has focused again on stakeholder participation in decision making in order to avert undesirable consequences.

Visioning – a heuristic device, which maps a “possibility space” - can be powerful instrument for inspiring societal actors to investigate different problem definitions, test alternative strategies, and find shared areas of agreement. Scenario building and backcasting, especially when used as a follow-up to visioning exercises, are also promising multi-stakeholder approaches. Both aim at creating blueprints to bridge the present and the future; scenarios create ‘alternative futures’ based on some form of trend-extrapolation and informed by an understanding of dominant drivers; in backcasting a future vision or normative scenario is followed by looking back in time and creating a strategy or action plan for proceeding from the present toward the desirable future.

A transition from a car-centered personal mobility system toward a sustainable mobility system cannot be designed as a blueprint, owing to its complexity. Rather, a broad societal learning process is needed, with a focus on the system as a whole: its spatial characteristics, the infrastructural and technologic options, individual needs for mobility and access, cultural norms, and institutions, as well as their mutual interdependence. This, in turn, requires paying more attention to question of how to infuse the present socio-technical system of individual mobility with a greater capacity to reframe problems, to synthesize the accumulated cross-disciplinary and cross-institutional knowledge, and to set and articulate alternative policy and technology trajectories. This, in essence, is our framing of “transition management.”

The policy implications of these conclusions are that more attention and funding should be allocated to multi-stakeholder visioning processes, interactive backcasting exercises, small-scale experimentation with promising socio-technical solutions, and “reflexive” monitoring [Grin et al, 2005] of these experiments in a way that enables and diffuses learning. In addition, strong communication and education policies are necessary. Above all a strong government commitment is necessary to reduce CO2 emissions to specific target levels by a variety of technical and non-technical instruments. In this way an innovative climate will be nurtured both at the supply and the demand side.

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