

RESEARCH ARTICLE

Ectogenesis: An example of science fiction's relevance to technology assessment

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Abstract • Following groundbreaking advances such as the successful cultivation of a sheep in the early fetal stage in a 'biobag' – an artificial womb –, public debate about ectogenesis in humans has intensified in recent years. We analyze depictions of ectogenesis in science fiction works, asking what can be learnt for technology assessment. The works are considered under the reproductive justice framework to identify negative and positive application scenarios. The results illustrate the high relevance of sociopolitical and economic conditions and thus of open ethical and regulatory debates and democratic legal frameworks when dealing with emerging technologies. From a methodological perspective, the example of ectogenesis confirms that the triad of utopianism/dystopianism, technofuturism, and science fiction is key to analyzing discourse on (bio)technologies.

Ektogenese: Ein Beispiel für die Relevanz der Science-Fiction für die Technikfolgenabschätzung

Zusammenfassung • Nach bahnbrechenden Fortschritten wie der erfolgreichen Züchtung eines Schafs im frühen Fötalstadium in einem 'Biobag' – einer künstlichen Gebärmutter – hat sich die öffentliche Debatte über die Ektogenese beim Menschen in den letzten Jahren intensiviert. Wir analysieren Darstellungen der Ektogenese in Science-Fiction-Werken und fragen, was daraus für die Technikfolgenabschätzung gelernt werden kann. Die Werke werden aus der Perspektive der reproduktiven Gerechtigkeit betrachtet, um negative und positive Anwendungsszenarien zu ermitteln. Die Ergebnisse verdeutlichen die hohe Relevanz soziopolitischer und wirtschaftlicher Bedingungen – und damit auch offener ethisch-regulatorischer Debatten und demokratischer Rechtsrahmen – im Umgang mit neuen Technologien. Aus metho-

dologischer Sicht bestätigt das Beispiel der Ektogenese, dass die Trias aus Utopie/Dystopie, Technofuturismus und Science-Fiction für die Analyse des Diskurses über (Bio-)Technologien von zentraler Bedeutung ist.

Keywords • science fiction, technology assessment, technofuturism, utopianism, feminism

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Introduction

In 2017, researchers at the Children's Hospital of Philadelphia reported that they had succeeded in keeping a sheep alive in the early fetal stage in a 'biobag,' an artificial womb, until it was ready to be born (Partridge et al. 2017). There is debate about when such technology could be available for extremely premature human births (Kozlov 2023). These developments have brought new relevance to the debate on human ectogenesis, the realization of the complete reproductive process, including fertilization of the egg, outside the woman's body. Complete ectogenesis is still a long way off due to significant technological challenges, but this vision has never appeared as realistic as it does today.

Complete ectogenesis is the focus of the 2022 YouTube concept video *EctoLife* by science communicator Hashem Al-Ghaili, which has garnered around 3.5 million views (Al-Ghaili 2022). The video depicts a factory producing up to 30,000 babies per year through in vitro fertilization in capsules. Initially aimed at those unable to have children naturally or wishing to avoid pregnancy, an 'elite package' offers CRISPR/Cas9 genetic modifications – from skin and eye color to height and intelligence. *EctoLife* is also presented as a solution for countries facing population decline. Its uncritical portrayal of ectogenesis sparked comparisons to dystopias like *Gattaca* (Pichler 2022). Beyond the sterile artificial intelligence (AI)-controlled facility, concerns include genetic optimization, the

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uniformity of the babies, and the potential for governmental abuse.

From a technology assessment (TA) perspective, the chances and risks of ectogenesis as an emerging technology deserve attention. While it is still speculative, science fiction provides detailed portrayals of its sociocultural effects and ethical aspects (Steinmüller 2016; Mehnert 2023). Hermeneutic TA offers orientational knowledge rather than prognostic or scenario-based guidance about our current social and individual fears and hopes in relation to new technologies. This improves the conditions “for democratic debates and decisions about the future to be conducted in a more informed, transparent, and open manner” (Grunwald 2015, p. 68). Science fiction’s more playful approach compared to foresight, future studies or technofuturistic essays (Coenen 2004) can stimulate unconventional thinking and discourse about possible futures (Borrmann et al. 2023) in which entrenched value conflicts have less influence. In general, art is (not only) in these regards important for hermeneutic TA.

From a technology assessment perspective, the chances and risks of ectogenesis as an emerging technology deserve attention.

We will first discuss early texts on ectogenesis, and then address science fiction works that explore the tension between feminist utopianism and capitalist integration. Afterwards, we will focus on works in which authoritarian regimes use ectogenesis to maintain their power, before examining those that deal with the abuse of power by individuals. The conclusion summarizes the results for TA. We use the reproductive justice framework – based on universal human rights and encompassing bodily autonomy, the right to have or not have children, and parenting in safe, sustainable communities, linking reproductive rights with social justice, including family structures, contraception, and reproductive technologies (SisterSong 2023; Ross and Solinger 2017) – to assess how ectogenesis is depicted.

Ectogenesis between technofuturism, dystopia, and feminist utopianism

A phenomenon epitomized by J. D. Bernal’s *The World, the Flesh and the Devil* (1929) (Manuel and Manuel 1980; Slusser 2009) and often overlooked in utopian and science fiction studies is the genre of largely non-fictional technofuturist essays and books. Since the 2000s, it has been increasingly addressed in such fields as philosophy, TA, media studies, and theology, especially in connection with transhumanism. While H. G. Wells was a pioneer of both futurist essays and science fiction, technofuturist essays emerged in the first third of the 20th century as a distinct phenomenon, separate from early science fiction or utopian/dystopian novels (Coenen 2014, 2015; Saage 2011),

focusing more on prognosis than on social critique. Bernal and, before him and more frequently, his friend and comrade J. B. S. Haldane, wrote such essays to predict sociotechnical futures based on the best available scientific and scholarly knowledge of their time. These essays combined clear analyses of the state of the art in science and technology with serious attempts at prediction, including visions in which the fulfillment of Christian hopes is combined with communist beliefs in a rationally organized world. They offered their readers – many of whom were workers – witty and entertaining social commentary and science education and also provided an important context for the emergence of the concept of ectogenesis (Ferreira 2009).

In 1923, Haldane delivered *Daedalus, or Science and the Future* at the Heretics Society, discussing the revolutionary potential of science and technology. It opens with a scene from World War I, the defining shock for us as humanity in our relationship to technology. This is followed by a scathing critique of Christian conservatives and capitalism, presented with the pride

of an excellent member of the rising functional elite of natural scientists and the disgust for destruction and unscientific sentiments. The introduction at the same time justifies futurist and utopian essay-writing, with reference to two of its early masters, Samuel Butler and H. G. Wells. The essay also contains a critique of the deplorable state of technology and a plea to use art to foster technoscientific progress. Taking an exaggerated example of future ‘human enhancement’ as its starting point, the work examines the revolutionary role of biochemistry in society. Its eugenic-transhumanist vision of the future is, at least implicitly, consistently directed against Christianity. In contrast to his later essays, *Daedalus* is less a communist futurist work than a culturally revolutionary one.

In our context a short passage is particularly relevant. Haldane presents it as a ‘myth’, keeping with the view he had already expressed in the introduction that mythopoesis is necessary. In this long pseudo-quotation from a future handbook on the history of biology in the 19th and 20th centuries, a biotechnological invention is described that changes the course of world history. Here, Haldane coins the term “ectogenesis” (Haldane 1924, p. 64), imagining children gestated entirely outside the female body starting in 1951, with ectogenesis becoming the standard by 1968. He also argued that if “reproduction is once completely separated from sexual love, mankind will be free in an altogether new sense” (Haldane 1924, p. 64). Haldane linked ectogenesis to global improvement in health and society and also advocated eugenics to ensure that only the “superior” reproduced – but in the year 1927 stressed that eugenics should promote talent regardless of class, embedding ectogenesis in a transhumanist

vision where individuals are subordinate to humanity's destiny (Haldane 1930, pp. 311–312).

The highly remarkable but long-forgotten “dys-/utopia” (Squier 1994, p. 127) *Man's World* (1926) by Haldane's wife Charlotte, née Franken, also featured the theme of ectogenesis. This novel explored it in a technocratic society in which male scientists dominate while women are valued mainly as mothers, organized into eugenic associations, with childless women having the role of ‘neuters.’ The novel anticipates Aldous Huxley's *Brave New World* (1932), depicting state-controlled sex selection and reproduction and scientists aiming for complete ectogenesis to render most women obsolete except elite “female types” or a singular “human termite queen” (Haldane 1926, p. 61). *Man's*

Piercy drew on Shulamith Firestone's *The Dialectic of Sex* (1970), which regarded artificial reproduction as a step toward gender equality, provided reproductive responsibilities are restructured. Firestone argued that women's oppression stems from the biological basis of reproduction, but warned that technological dissolution of this basis could worsen exploitation under patriarchal systems. Feminist visions thus emphasize that ectogenesis can only contribute to equality if accompanied by profound sociopolitical change. Contemporary concerns include the risk that, in today's sexist or capitalist societies, ectogenesis could reinforce male power, marginalize women, or exacerbate socioeconomic inequalities (Rudy 1997; Gregoriatti 2021; Cavaliere 2019).

In more recent feminist utopian visions, ectogenesis functions not as a driver of social change, but as its companion.

World, like related non-fiction works by her, oscillates between glorifying a scientifically based technocracy and criticizing it, between feminism and anti-feminism, and between utopia and dystopia. The novel was not only an important fictional contribution to the visionary debate on ectogenesis in the 1920s (on this debate, Squier 1994, pp. 63–93), but can also be seen as a groundbreaking masterpiece of the 20th century dystopian novel genre, preceded only by Yevgeny Zamyatin's *We* (completed in 1920), and as an important engagement with the early technofuturism of her husband.

Another futuristic work, *The Age of Automata* (1930) by chemist Ludwig Dexheimer (pseud. Ri Tokko), envisions a pacifist world with innovations including the “Genetic Station,” producing one million people annually in “uterators” (Tokko 2004, pp. 681–696). The station enforces eugenics, killing disabled babies, while presenting ectogenesis as a benefit for women, freeing them from the physical burdens of reproduction and transforming gender relations toward greater equality.

Even if the three works have (quasi-)utopian elements, they contradict not only ethical principles that have been developed later in the 20th century but also modern categories of reproductive justice, as a scientific elite decides who is allowed to have children on the basis of biological considerations. However, ectogenesis is only one element of a broader technofuturistic perspective in these works.

In more recent feminist utopian visions, ectogenesis functions not as a driver of social change, but as its companion. Marge Piercy's 1976 novel *Woman on the Edge of Time* contrasts a present marked by gender inequality with a utopian future world, where children are cared for collectively by three ‘mems’ of both sexes and attend free childcare facilities with qualified, well-paid staff. Babies are gestated in ‘brooders’ and grow in ‘birthing chambers,’ eliminating fixed gender roles, unwanted pregnancies, and promoting reproductive justice.

These concerns are explored in three science fiction novels set in a future Britain with a privatized, market-oriented National Health Service. As McFarlane (2022) notes, full artificial womb technology improves reproductive justice in some cases – enabling women greater control over pregnancies, queer and infertile people to have children, and genetically at-risk individuals to produce healthy offspring. Yet access is uneven, with corporate and privatized systems reinforcing social hierarchies. Smith's *Baby X* (2016), Sedgwick's *The Growing Season* (2017), and Charnock's *Dreams Before the Start of Time* (2017) depict how reproductive technologies can be co-opted into pre-existing inequalities, commodifying embryos, fetuses, and parenthood itself. Even Charnock's ostensibly utopian vision shows parents constrained by sociotechnical pressures (Buran 2022). The 2023 science fiction romance *The Pod Generation* similarly highlights the dual potential of ectogenesis: increasing autonomy while imposing new pressures. These works illustrate how ectogenesis has long served less as a purely technological prediction than as a lens through which shifting hopes, anxieties, and power structures surrounding reproduction, gender, and social order are imagined.

Ectogenesis as a tool for maintaining power in authoritarian regimes

Ectogenesis finds a completely dystopian application in science fiction works, when it is used by authoritarian systems to maintain power. In this situation, reproduction is not subject to standards of justice, just as the human rights on which reproductive justice is based are circumvented. Huxley's influential *Brave New World* (1932) turns the quasi-utopian vision of ectogenesis in Haldane's *Daedalus* into a dystopia. The fictional society is a highly centralized, technologically advanced world state 500

years in the future that exercises total control over life, behavior, and thought. Emotional bonds and individuality are suppressed as threats to social stability, which is based on the pacifying drug *Soma* and a rigid class system in which people are socially conditioned from birth. Humans are artificially created in ‘hatcheries,’ where fetuses are engineered to fit predetermined functions and sustain the class hierarchy. Huxley criticizes certain uses of technology, science-based technocracy, the pursuit of pleasure at the expense of freedom and dehumanization. The problem is not ectogenesis itself, but its use by an oppressive state to preserve hierarchy and eliminate emotional family ties.

In Matthias Oden’s 2017 German novel *Junktown*, the population also lives in a permanent collective drug frenzy. A ‘consumption revolution’ has replaced the old system. People are encouraged to consume as much as possible and are manipulated and made compliant with the help of state-prescribed drugs. Babies are produced by the hundreds in absurdly huge machines called ‘breeding mothers’. Due to constant drug consumption, people are physically and psychologically incapable of having children. For this reason, many tasks relevant to society are performed by machines or by people specially bred for this purpose. Breeding machines enable a division into specific human classes according to status and usefulness to society through genetic manipulation of the babies – very similar to Huxley’s vision. Ectogenesis becomes a symbol of dehumanization and is deliberately used by those in power to maintain an unfree system.

that these biological parents will form heteronormative families to raise their children. State-controlled reproduction is presented as dystopian, the enforcement of traditional family structures as normal. The real problem is not ectogenesis itself, but its use by an authoritarian ruling elite.

Across these examples, ectogenesis functions less as a technological threat in itself than as a mirror of political systems that instrumentalize reproduction to consolidate power and suppress human autonomy.

Enforcement of personal ambitions for power through ectogenesis

Another aspect of the use of ectogenesis is the possibility for individuals or small groups with unregulated access to the technology to determine the fate of many people or even humanity. In the 2019 film *I Am Mother*, humanity has been wiped out by an unspecified catastrophe, possibly caused by machines. In a vast automated bunker storing thousands of embryos, a robot named ‘Mother’ begins to repopulate Earth. She selects an embryo, nurtures it in an artificial womb, and raises the resulting girl as her own. Over time, it becomes clear that Mother is an advanced AI manipulating the girl to realize her plan of repopulating the world with ethically ‘superior’ humans. In Laura Lam’s 2020 novel *Goldilocks*, five female astronauts hijack a NASA spacecraft in the near future to establish a human colony on a distant

Ectogenesis becomes a symbol of dehumanization.

Another example is the *Matrix* film series (starting 1999), in which most of humanity is unknowingly ruled by machines. After a war between humans and advanced AI in the early 21st century, the machines enslave humanity, keeping people alive in capsules to harvest their bioelectrical energy. To pacify them, they create a shared virtual reality – the Matrix – simulating life in 1999, where humans exist as digital avatars. To sustain this energy system, the machines must also produce new humans, which apparently happens through ectogenesis: In the first film, we see a human fetus in a capsule resembling an artificial womb, symbolizing total control over the dominated.

In Marion Herzog’s 2021 German novel *Algorytmica*, humanity lives entirely within a simulation. Set in the 24th century, the survivors of a global ecocide inhabit underground bunkers known as ‘arks,’ where they survive in small cells and exist as avatars. Unlike in *The Matrix*, people are aware of their situation, but powerless to change it. Natural conception is no longer possible. Ectogenesis becomes dystopian when the government turns it into a eugenics program: due to limited space and resources, only selected genes may be passed on. Initially, citizens can still apply to use their own eggs and sperm, but later, partners are assigned according to genetic compatibility. The regime assumes

planet and build a more just world. They leave behind a ravaged Earth and an increasingly repressive U.S. government that prevents them from carrying out the mission legally. Despite these ideals, the mission’s leader, wealthy entrepreneur Valerie Black, secretly brings thousands of frozen embryos on board to be matured through ectogenesis and form the new population. Thus, artificial womb technology itself is not depicted as dystopian. Rather “it is the misuse of this technology as a form of population control to remake humanity in Valerie’s image that is the ethical issue at play” (Tongue 2022, p. 104). In both examples, unease arises from the combination of population control and the idea of moral superiority – whether exercised by an AI or a powerful individual. Ectogenesis enables individuals to create life on a large scale for their own purposes when left unregulated.

In their 1982 novel *Andymon: Eine Weltraumutopie*, Angela and Karlheinz Steinmüller explore an alternative approach to colonizing another planet. About twenty years before an automated spaceship arrives, humans of diverse ethnicities are created from frozen fertilized eggs in incubators and raised by robots to prepare for the mission. The novel serves as a parable for democratic co-existence, with reproductive justice central: Settlers can choose whether to continue conceiving children in incubators or natu-

rally, and decide the environment in which their children grow up.

Another aspect of ectogenesis involves not only growing embryos into babies but also creating fully developed humans, often in unregulated systems or through illegal corporate practices. A striking example is the 2005 film *The Island*, set in 2019. Bernard Merrick, a bioscientist aiming to eradicate disease, finances his research by producing clones for wealthy clients as organ donors or surrogate mothers. These ‘agnates’ are grown from clients’ genetic material in artificial sacs and mature within twelve months. Although eugenics laws require clones to remain vegetative, he discovers their organs stay viable only if they reach conscious-

power-driven scenarios. Science fiction provides visions of the future under different conditions of technology use.

The examples reveal the fears and hopes associated with ectogenesis. The fears reflect concerns about growing inequality in increasingly privatized healthcare systems, violent ableism and potential abuse in power structures without democratic control. The hope is for increased reproductive and gender equality in a system that sets goals for a more just society. From a TA perspective, science fiction works can be read as expressions of the need for comprehensive and open ethico-regulatory debates and democratic frameworks when considering the use of such technologies.

Science fiction provides visions of the future under different conditions of technology use.

ness, a fact he conceals. Unaware of their fate, clones live in a simulated facility until harvested for organs, often resulting in mutilation or death. Merrick embodies the ‘mad scientist’ archetype, pursuing a godlike mission without ethics.

In the *Blade Runner* franchise, it is adult replicants – organically produced and indistinguishable from humans – who embody artificial life. In Ridley Scott’s 1982 *Blade Runner*, the Tyrell Corporation creates replicants for asteroid mining, limiting their lifespan to four years to prevent emotional development. In *Blade Runner 2049* (2017), replicants are grown in translucent biobags, emerging fully formed from artificial wombs under Tyrell’s successor, the Wallace Corporation. CEO Niander Wallace seeks self-replicating models, believing natural reproduction essential for interstellar colonization. When his experiment fails, he kills the newborn replicant – striking her abdomen, the symbolic site of reproduction. Like Merrick, Wallace profits from an unethical model and envisions himself as a godlike creator.

In both *The Island* and *Blade Runner*, ectogenesis is used to produce beings who are then forced into natural reproduction. Reproductive justice is entirely denied, with corporate leaders exercising godlike control. As before, fantasies of omnipotence are projected onto the power to create life.

Conclusion

Although complete ectogenesis is not yet feasible, ongoing research justifies building basic knowledge about it as a potential emerging technology. Ectogenesis is “an example of how the same technology may be envisioned to produce both dystopian and utopian futures” (Vint 2021, p. 100). Whether fictional applications appear positive or negative depends on sociopolitical and economic contexts. For instance, the ‘Artificial Womb Facility’ in the concept film *EctoLife* is inherently questionable, but it becomes truly dystopian only in market-driven, authoritarian, or

Methodologically, the example of ectogenesis shows, already with regard to the 1920s, that it is advisable for hermeneutic TA to always consider the influence of the triad of closely related genres of science fiction, utopian/dystopian fictional works and transhumanist and other technofuturist non-fiction when analyzing new and emerging (bio-)technologies.

Technologies in science fiction often function as metaphors and projection surfaces (Hermann 2023). Ectogenesis can be read as a powerful image for the broader development of reproductive technologies: Questions of reproductive justice extend to advances in prenatal diagnostics, genetic manipulation, or biobags, developments that are already near reality. According to Sophie Lewis, techniques such as biobags for extremely premature births have nothing to do with the struggle for reproductive justice in our current world marked by injustice, “but I would love to one day see the queer gestational commune in which ‘bio-bags’ of some kind enabled gestators to pause, share, transfer, redistribute, and walk away from pregnancies” (Lewis 2019).

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