

## Smart Banknote Functionality: Critical Features and Production Challenges

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### Executive Summary

- A smart banknote is a physical banknote on a paper or polymer substrate that can communicate with an electronic network.
- The purpose of a smart banknote is to bridge the division between traditional cash and electronic money, combining the advantages of both technologies.
- The idea of a smart banknote arose in 2010, and since that time eight models, prototypes, and issuances have been developed.
- All smart banknotes share six kinds of features: Type of Network Access Device, the Number of Uses, the Substrate, the Currency Type, the Offline Value Indicator, and the Offline Authenticating Feature.
- The ideal smart banknote must use chip technology embedded in a paper or polymer substrate and have on its surface features that allow a user to determine its value and authenticity when the note is not connected to an electronic network.
- Developing a smart banknote for mass use faces technological challenges, but solutions are within reach.

### Introduction

A smart banknote is a physical banknote on a paper or polymer substrate that can communicate with an electronic network. A smart banknote is denominated and has the physical properties of a traditional banknote in size, feel, appearance, and etc. It is not a rigid, plastic card such as may be used in present credit or debit transactions. The purpose of a smart banknote is to act as a hybrid that can function either as a definitive or an electronic instrument, depending upon the immediate need. Such functionality will allow a smart banknote to act as a transitional device between traditional payment systems and electronic and crypto-based payment systems.

Published work on smart banknotes first appears in 2010. By that year, and the rise of cryptocurrencies, thinking about electronic features on banknotes had expanded from new concepts of security features to include the thoughts of a smart banknote as acting as a hybrid of traditional banknotes and cryptocurrencies. Over the past decade, these thoughts have been expanded and put into practical application, although in different forms. One purpose of this paper is to review the thought and technology behind former and present smart banknotes and to find the common features among them, creating a form of smart banknote taxonomy in the process. It will also explore those issues not raised by past and present smart banknotes that are necessary to make them fully functional on a mass scale such as the currency of a central bank. In sum, this paper examines the functional aspects of smart banknotes.

### Models, Prototypes, and Issuances

Our first task is to review the current state of the smart banknote field. This will be done in chronological order, beginning with the early concepts developed for the Bill & Melinda Gates Foundation by Ignacio Mas as Deputy Director for Financial Services for the Poor and Consult Hyperion, represented by Paul Makin and Andrew Whitcombe who are credited with creating the term “smart banknote.”<sup>1</sup>

This paper differentiates between stages of smart banknote development using the terms models, prototypes, and issues. A model smart banknote is one that never proceeded beyond the conceptual stage. No actual banknote was produced as a proof of concept. A smart banknote prototype is an actual banknote produced to test a smart banknote concept. It is possible that a small number of these notes were sold for use, but this is unknown. A smart banknote issue is one that is known to have been sold in large quantities (hundreds) for everyday use.

### Ignacio Mas Model

Futurist Ignacio Mas was one of the first theorists of smart banknotes. In a 2010 paper, he started with the premise that the continued existence of traditional banknotes was inevitable, pointing to cash’s benefits of universal acceptance, store of value, immediate

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<sup>1</sup> Ignacio Mas, “Smart Banknotes: A Proposal for Bank Notes that Bridge the Gap Between Physical and Electronic Money,” *The Futurist*, 5, 1 (Jan-Feb 2011), *passim*, [papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1687368](http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687368); “Smart Banknote Design Competition,” *Consult Hyperion* (12 January 2011), URL: [chyp.com/2011/01/12/smart-banknote-design-competition/](http://chyp.com/2011/01/12/smart-banknote-design-competition/) (accessed 6 October 2020).

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transactions, fixed denominations (allowing for budgeting and minimal loss if the note is lost or stolen), and anonymity in transactions, acting as a bearer instrument.<sup>2</sup> Also, the physicality of notes, he argued, aided in the everyday use, handling, and budgeting of money.<sup>3</sup>

The purpose of a smart banknote was to minimize the problems and costs associated with traditional banknotes. These included the inability to make remote payments, the cost of access (via ATMs) and central bank distribution, the problem of individual and institutional safe-keeping, and the cash holder's propensity to spend smaller denominations.

Mas argued that electronic money overcame these problems at the expense of anonymity and the need for access to an electronic network.<sup>4</sup> He did not see smart banknotes as a transitional device between a cash-money economy and an electronic-money one. Instead, he wanted to use technology to reduce the cost of cash co-existing with electronic money and to allow the inclusion of those people with limited access to an electronic network.<sup>5</sup>

The way to do this, he envisioned, was through a smart banknote that could send and receive a set amount of value, the amount denominated on the note, over an electronic network.

These smart banknotes were originally envisioned as traditional, denominated banknotes with RFID chips embedded in them. The chips allowed the smart banknotes to communicate with electronic networks and to "activate" or "deactivate" the note, meaning to validate or invalidate the banknote's face value. It was envisioned that smart banknotes could repeatedly move between these states, having the denominated value of the note transferred to and from the smart banknote as needed. And, the note would physically show without connection to an electronic network whether it was activated or deactivated, whether it had value or not.<sup>6</sup>

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<sup>2</sup> Ignacio Mas, "Smart Banknotes: A Proposal for Bank Notes that Bridge the Gap Between Physical and Electronic Money," *The Futurist*, 5, 1 (Jan-Feb 2011): 1-2, [papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1687368](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687368); Ignacio Mas, "Smart Banknotes Will Be the Cash of the Future," *Quartz* (25 September 2018), URL: <https://qz.com/1381266/smart-banknotes-will-be-the-cash-of-the-future/>; Ignacio Mas, "Making Digital Money More Like Cash," 16 April 2020, 1, ms; Ignacio Mas in discussion with Franklin Noll, 14 October 2020.

<sup>3</sup> Ignacio Mas, "Making Digital Money More Like Cash," 16 April 2020, 2-3, ms.

<sup>4</sup> Ignacio Mas, "Smart Banknotes Will Be the Cash of the Future," *Quartz* (25 September 2018), URL: <https://qz.com/1381266/smart-banknotes-will-be-the-cash-of-the-future/>.

<sup>5</sup> Ignacio Mas, "Smart Banknotes: A Proposal for Bank Notes that Bridge the Gap Between Physical and Electronic Money," *The Futurist*, 5, 1 (Jan-Feb 2011): 2-3, [papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1687368](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687368); Ignacio Mas in discussion with Franklin Noll, 14 October 2020.

<sup>6</sup> Ignacio Mas, "Smart Banknotes: A Proposal for Bank Notes that Bridge the Gap Between Physical and Electronic Money," *The Futurist*, 5, 1 (Jan-Feb 2011): 3-4, [papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1687368](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687368); Sara Corley, "LISTEN NOW: Smart Banknotes and the Future of Money," *Digital Frontiers Institute* (29 March 2019), URL: [digitalfrontiersinstitute.org/2019/03/29/webinar-smart-banknotes-ignacio-mas](https://digitalfrontiersinstitute.org/2019/03/29/webinar-smart-banknotes-ignacio-mas) (accessed 6 October 2020); Consult Hyperion, "Smart Note Feasibility Study" (PowerPoint presentation, Bill & Melinda Gates

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The smart banknotes would communicate with a bank's central network via a mobile phone or POS terminal. Using this payment network, the user would approve a movement of the denominated amount of an activated note to the user's bank account or to a merchant's account. The smart banknote would then become deactivated. This state would be apparent on the face of the note in some way: perhaps the ink changed color or grayed out.<sup>7</sup> (This referred to an electronic ink, E Ink, that was only available in grayscale at the time. The Hyperion Consult model, discussed below also used electronic ink.) The bank's payment network could also be used to reactivate the note by moving the denominated amount of the bill from the user's account to the smart banknote. Accordingly, the color of the note would return to its original brilliance.<sup>8</sup>

This conception of a smart banknote was later modified by Mas. Instead of smart banknotes pre-printed with a set denomination, the deactivated notes would be non-denominated, gaining their denomination when activated and loaded with a value. The smart banknote could be loaded with any denomination available for its currency with the amount displayed via E Ink on the face of the note.<sup>9</sup>

When not connected to a network, an activated note could be used as a traditional banknote. It would be used in transactions at its denominated value. As with cash, payments would be immediate and anonymous. The activated note would be a bearer instrument with value belonging to the holder who could connect it to a network to electronically transfer its value or pass it along in another personal transaction off the network.

The RFID chip in the note, according to Mas, would "hold an encrypted unique serial number" that could only be read when connected to a payment network. This would ensure authenticity but also allow for the tracking of the note through transactions and locations.<sup>10</sup>

Central banks issuing these smart banknotes might save money by transporting deactivated notes to banks and other intermediaries, including individual merchants,

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Foundation, September 2009); Consult Hyperion, "Smart Note Feasibility Study" (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>7</sup> Ignacio Mas, "Smart Banknotes Will Be the Cash of the Future," *Quartz* (25 September 2018), URL: <https://qz.com/1381266/smart-banknotes-will-be-the-cash-of-the-future/>; Consult Hyperion, "Smart Note Feasibility Study" (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>8</sup> Ignacio Mas, "Smart Banknotes Will Be the Cash of the Future," *Quartz* (25 September 2018), URL: <https://qz.com/1381266/smart-banknotes-will-be-the-cash-of-the-future/>.

<sup>9</sup> Ignacio Mas in discussion with Franklin Noll, 14 October 2020.

<sup>10</sup> Ignacio Mas, "Smart Banknotes: A Proposal for Bank Notes that Bridge the Gap Between Physical and Electronic Money," *The Futurist*, 5, 1 (Jan-Feb 2011): 4, [papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1687368](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687368); Sara Corley, "LISTEN NOW: Smart Banknotes and the Future of Money," *Digital Frontiers Institute* (29 March 2019), URL: [digitalfrontiersinstitute.org/2019/03/29/webinar-smart-banknotes-ignacio-mas](https://digitalfrontiersinstitute.org/2019/03/29/webinar-smart-banknotes-ignacio-mas) (accessed 6 October 2020).

which would then be responsible for activating the notes before issuance.<sup>11</sup> The smart banknotes could also be introduced gradually into the existing pool of banknotes. Otherwise, central banks would have to provide the applications, hardware, and network necessary to make the smart banknotes functional. Further, Mas argued that the needed RFID chips could be added to existing banknotes with their paper or polymer substrates.<sup>12</sup>

### Consult Hyperion Model

The Consult Hyperion model that appeared at roughly the same time as the Ignacio Mas modeled, being based on the same research effort at the Gates Foundation that focused on financial inclusion and bridging the gap between physical and electronic money, also included an RFID chip in a banknote with a polymer substrate.<sup>13</sup> This chip would ensure the authenticity of the note and be used to communicate with an electronic network.<sup>14</sup>

The elements of this smart banknote included this chip with its antenna, sensors, a power supply, and a display.<sup>15</sup> The display would use electronic ink or E Ink. (This ink changes appearance when an electrical charge is applied and can be printed on almost any surface.) This E Ink would be used to display the value of the smart banknote and would be critical to the functioning of the note.

Consult Hyperion envisioned a smart banknote that acted more as a debit card. And, while the note would presumably be denominated with a maximum value, value could be subtracted from the smart banknote via electronic transactions. The current value would be displayed on the note via the E Ink. The functioning of the Consult Hyperion smart banknote was laid out in an example:

How would such a note be used? Well, imagine that you have a banknote that says “£10” on it. You [take it] to the coffee shop and spend £1.50 on a coffee. You tap the note on the till to pay, and the display now changes to say “£8.50”. When you get to work, your friend reminds you that you owe him £8 from the pub. You give him the note and he gives you a 50p coin in change. Your friend can absolutely

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<sup>11</sup> Ignacio Mas, “Smart Banknotes Will Be the Cash of the Future,” *Quartz* (25 September 2018), URL: <https://qz.com/1381266/smart-banknotes-will-be-the-cash-of-the-future/>; Ignacio Mas in discussion with Franklin Noll, 14 October 2020.

<sup>12</sup> Ignacio Mas, “Smart Banknotes: A Proposal for Bank Notes that Bridge the Gap Between Physical and Electronic Money,” *The Futurist*, 5, 1 (Jan-Feb 2011): 4, [papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1687368](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1687368); Mas also raises the option of a print-at-home banknote, Ignacio Mas, “Making Digital Money More Like Cash,” 16 April 2020, 3-4, ms; Ignacio Mas in discussion with Franklin Noll, 14 October 2020.

<sup>13</sup> Paul Makin, “Smart Banknotes: Bridging the Divide” (PowerPoint presentation, 13<sup>th</sup> Digital Money Forum, London, March 2010); Consult Hyperion, “Smart Note Feasibility Study” (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>14</sup> “Smart Banknote Design Competition,” *Consult Hyperion* (12 January 2011), URL: [chyp.com/2011/01/12/smart-banknote-design-competition/](http://chyp.com/2011/01/12/smart-banknote-design-competition/) (accessed 6 October 2020); “Plastic Banknotes,” *Consult Hyperion* (9 October 2013), URL: [chyp.com/2013/10/09/plastic-banknotes/](http://chyp.com/2013/10/09/plastic-banknotes/) (accessed 6 October 2020).

<sup>15</sup> Paul Makin, “Smart Banknotes: Bridging the Divide” (PowerPoint presentation, 13<sup>th</sup> Digital Money Forum, London, March 2010).

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trust that the value represented by the note is indeed £8.50 because the tamper-resistant chip and the cryptography it deploys make it impossible to counterfeit.<sup>16</sup>

The value of the note could also be increased back to its maximum face value through electronic transfers to the note from a bank account.<sup>17</sup>

Consult Hyperion argued that the use of a chip in the banknote would eliminate the need of other costly, more traditional security features such as intaglio printing, complex design, and holograms.<sup>18</sup> The chip would be all that was needed to ensure the authenticity of the note. However, Consult Hyperion recognized that it would be difficult for a user to judge the authenticity of a smart banknote if no electronic network was available.<sup>19</sup> Consult Hyperion was also concerned about how to prevent the “virtual pick-pocketing” of the RFID chip.<sup>20</sup>

In any case, a plastic substrate, it argued, was needed to allow for the application of electronics and E Ink.<sup>21</sup> Also, like the Ignacio Mas smart banknote, it was believed that central banks could save money by transporting deactivated notes to banks and other intermediaries, which would then be responsible for activating the notes before issuance.<sup>22</sup> In 2010, Consult Hyperion estimated that the technology needed to mass produce such smart banknotes would only be available by 2020 or 2025.<sup>23</sup>

At the time, Consult Hyperion also concluded that its banknote could take on any shape, abandoning traditional banknote characteristics.<sup>24</sup> And, it put forward a card-type smart banknote that would not require the advanced technology needed for a traditional banknote-type smart banknote. However, it saw that the drawbacks to this card-type design could imperil the mission of a smart banknote as it would be less socially acceptable to those used to traditional banknotes and it would not be compatible with the

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<sup>16</sup> “Smart Banknote Design Competition,” *Consult Hyperion* (12 January 2011), URL: [chyp.com/2011/01/12/smart-banknote-design-competition/](http://chyp.com/2011/01/12/smart-banknote-design-competition/) (accessed 6 October 2020).

<sup>17</sup> “Plastic Banknotes,” *Consult Hyperion* (9 October 2013), URL: [chyp.com/2013/10/09/plastic-banknotes/](http://chyp.com/2013/10/09/plastic-banknotes/) (accessed 6 October 2020).

<sup>18</sup> “Smart Banknote Design Competition,” *Consult Hyperion* (12 January 2011), URL: [chyp.com/2011/01/12/smart-banknote-design-competition/](http://chyp.com/2011/01/12/smart-banknote-design-competition/) (accessed 6 October 2020).

<sup>19</sup> Consult Hyperion, “Smart Note Feasibility Study” (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>20</sup> Consult Hyperion, “Smart Note Feasibility Study” (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>21</sup> “Plastic Banknotes,” *Consult Hyperion* (9 October 2013), URL: [chyp.com/2013/10/09/plastic-banknotes/](http://chyp.com/2013/10/09/plastic-banknotes/) (accessed 6 October 2020).

<sup>22</sup> “Plastic Banknotes,” *Consult Hyperion* (9 October 2013), URL: [chyp.com/2013/10/09/plastic-banknotes/](http://chyp.com/2013/10/09/plastic-banknotes/) (accessed 6 October 2020); Paul Makin, “Smart Banknotes: Bridging the Divide” (PowerPoint presentation, 13<sup>th</sup> Digital Money Forum, London, March 2010).

<sup>23</sup> Paul Makin, “Smart Banknotes: Bridging the Divide” (PowerPoint presentation, 13<sup>th</sup> Digital Money Forum, London, March 2010); Consult Hyperion, “Smart Note Feasibility Study” (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>24</sup> “Smart Banknote Design Competition,” *Consult Hyperion* (12 January 2011), URL: [chyp.com/2011/01/12/smart-banknote-design-competition/](http://chyp.com/2011/01/12/smart-banknote-design-competition/) (accessed 6 October 2020).

existing cash-handling infrastructure, which would result in massive resistance to its adoption by the cash-handling industry.<sup>25</sup>

### **bitbills Prototype**

The first prototype smart banknotes were built upon the conception of a paper wallet for Bitcoin. A paper wallet is a paper or polymer item that contains the private and public keys needed to access a single cryptocurrency address or account and the funds therein. It conveys no value unless connected to an electronic network.

However, the idea of a paper wallet was modified by creating a device that was denominated, allowing it to convey value without connection to the internet. In 2011, bitbills were designed as plastic cards denominated in Bitcoins. They bore public keys and private keys in the form of QR codes covered by tamper-evident stickers.<sup>26</sup> Unlike the earlier Ignacio Mas and Consult Hyperion models, there was no RFID chip involved.

The bitbill, it is assumed, would allow the user to transfer some or all of the denominated value in Bitcoin to an account for a purchase or other need. After use, it would not be evident on the card whether there was any balance on the card. All that would be known was that the card had been used because the sticker over the private key had been removed. It was probably the case that the entire denominated amount was transferred in one transaction.

This meant that once the card had been connected to an electronic network that it was basically useless in further hand to hand transactions and had to be considered burned or deactivated. Also, lacking a chip, a bitbill could not be recharged. It was largely a one-use device. However, as long as the bitbill had not been connected to a network and its tamper-evident sticker was intact, it could circulate as a denominated note at face value.

Given its functionality and physicality, there is little to distinguish a bitbill from a denominated gift card except for the denomination in Bitcoin. It is unknown whether any of these cards ever entered circulation. For this reason, it is considered a prototype rather than an issuance in this paper.

### **Bitcoin Suisse Crypto Certificates Issuances**

Bearing a greater resemblance to a banknote were notes issued by Bitcoin Suisse AG in 2013. Again, denominated in Bitcoins, these Bitcoin Suisse Crypto Certificates held a public key as a QR code (and in alphanumeric format) and a private key in alphanumeric format sandwiched between sheets of polymer paper, requiring destruction of the note to access it.<sup>27</sup> There was no RFID chip. These notes had serial numbers as well as passive and active security features.

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<sup>25</sup> Paul Makin, "Smart Banknotes: Bridging the Divide" (PowerPoint presentation, 13<sup>th</sup> Digital Money Forum, London, March 2010); Consult Hyperion, "Smart Note Feasibility Study" (PowerPoint presentation, Bill & Melinda Gates Foundation, September 2009).

<sup>26</sup> All that remains of this effort is a single webpage with an image of bitbills, URL: [bitbills.com](http://bitbills.com) (accessed 6 October 2020); Peter Sobotka, *Physical Bitcoins with Distributed Issuance and Offline Verification*, 29 October 2016, 1-2: [www.bitnotes.org/bitnotes.pdf](http://www.bitnotes.org/bitnotes.pdf).

<sup>27</sup> Sobotka, 2.

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As imagined by Ignacio Mas and Consult Hyperion, these smart banknotes were shipped deactivated or unloaded.<sup>28</sup> The purchaser of the note had to contact Bitcoin Suisse AG with the serial number and public key to load it with the denominated value.

Based upon paper wallets, these smart banknotes acted the same as previous bitbills. Bitcoin Suisse Crypto Certificates would allow the user to transfer some or all of the denominated value in Bitcoin to an account. It appears that Bitcoin Suisse AG assumed that the total amount would be moved.<sup>29</sup> The transfer of Bitcoin would be evident by the revealing of the private key printed on the note. However, if any balance were left on the note, this would be unknown to anyone viewing the bill.

So, like bitbills, these smart banknotes could be passed hand to hand until they were connected to an electronic network. After that, they had to be considered burned or deactivated. Also, lacking a chip, a Bitcoin Suisse Crypto Certificate could not be recharged. It was largely a one-use device.

In 2019, Bitcoin Suisse released a new series of Bitcoin Suisse Crypto Certificates. These smart banknotes are currently available in various denominations and cryptocurrencies and bear a private key under a scratch-off sticker.<sup>30</sup> These certificates act in the same way as the earlier series of smart banknotes. However, the 2019 series has advanced banknote security features such as optically variable ink, security ribbons, and UV ink.<sup>31</sup>

### BitNotes Prototype

In 2016, BitNotes appeared on the scene. Like bitbills and Bitcoin Suisse Crypto Certificates, these smart banknotes were based on Bitcoin, bore denominations, and used QR Codes to interface with an electronic network. However, BitNotes were designed to be printed at home using blanks provided by BitNote. And, actual physical prototypes were created. The point of this design was to increase security and anonymity by removing the manufacturer from providing the private key.<sup>32</sup>

The role of the manufacturer in producing a smart banknote was the overriding concern of BitNote. As we have seen with bitbills and Bitcoin Suisse Crypto Certificates, the

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<sup>28</sup> See the Proof of Purchase dated 2 February 2016 and pictured on “OG Bitcoin Suisse 1.0 BTC Loaded,” *Bitcoin Forum* (28 September 2019), URL: <https://bitcointalk.org/index.php?topic=5188329.0> (accessed 15 October 2020).

<sup>29</sup> Bitcoin Suisse, *Crypto Certificate Guide*, September 2020, URL: [https://files.bitcoinsuisse.com/assets/pdf/Crypto\\_Certificate\\_Guide\\_09.2020.pdf](https://files.bitcoinsuisse.com/assets/pdf/Crypto_Certificate_Guide_09.2020.pdf) (accessed 15 October 2020).

<sup>30</sup> “Crypto Certificates,” *Bitcoin Suisse*, URL: [www.bitcoinsuisse.com/crypto-certificates](http://www.bitcoinsuisse.com/crypto-certificates) (accessed 6 October 2020); “Bitcoin Suisse Launches All-New Crypto Certificate Series,” *Bitcoin Suisse*, URL: [www.bitcoinsuisse.com/news/bitcoin-suisse-launches-new-crypto-certificate-series](http://www.bitcoinsuisse.com/news/bitcoin-suisse-launches-new-crypto-certificate-series) (accessed 6 October 2020); “Bitcoin Suisse Launches All-New Crypto Certificate Series,” *Bitcoin Schweiz News* (20 September 2019), URL: [bitcoinnews.ch/17777/bitcoin-suisse-launches-all-new-crypto-certificate-series](http://bitcoinnews.ch/17777/bitcoin-suisse-launches-all-new-crypto-certificate-series).

<sup>31</sup> Bitcoin Suisse, *Crypto Certificate Guide*, September 2020, URL: [https://files.bitcoinsuisse.com/assets/pdf/Crypto\\_Certificate\\_Guide\\_09.2020.pdf](https://files.bitcoinsuisse.com/assets/pdf/Crypto_Certificate_Guide_09.2020.pdf) (accessed 15 October 2020).

<sup>32</sup> Sobotka, *passim*; BitNotes, URL: [www.bitnotes.org/](http://www.bitnotes.org/) (accessed 6 October 2020).



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manufacturer or vendor must provide the private key and load the denominated value onto the notes. This gives the seller access to and knowledge of the buyer's account, which is certainly frowned upon in the cryptocurrency world. Under the Ignacio Mas and Consult Hyperion models, value is transferred to a denominated smart banknote via a bank's or other intermediary's network from a central bank's or a user's account with the result that anonymity may or may not be ensured, depending upon the protocols involved in the transfer.

As stated above, BitNotes' solution to this problem was basically to have the buyer/user print the private keys onto the smart banknote and load value on it at home. (Ignacio Mas had a similar idea for privately printed notes.<sup>33</sup>) BitNote envisioned a system wherein a user would buy a sheet of denominated smart banknotes from a manufacturer. These notes would each hold a public and a private key in QR code format, the private key being under a security device. Then, using BitNote software, the user would send the needed Bitcoin to an address created from the smart banknote's public key and a new private key generated by the user. This second private key would be printed onto the paper BitNote by the user. With this action, the smart banknote was completed with value loaded onto it. At this point, the BitNote could be passed hand to hand.<sup>34</sup>

To redeem the note, the foil over the private key originally printed on the note by the manufacture would be removed. And, using BitNote software, this private key along with the second private key and the public key would be used to access the loaded Bitcoin.

As with all the paper-wallet models discussed so far (bitbills and Bitcoin Suisse Crypto Certificates), BitNotes could only be used once. Lacking chips, they could not be recharged. These notes also resulted in a fair amount of complexity for the user who had to obtain the software, the blank notes, and a printer. The user also had to perform multiple electronic operations to "issue" the BitNote.

### Andrei Lipkin Model

Andrei Lipkin is a banknote designer, who in 2017 began creating models for smart banknotes or "cryptobanknotes," as he calls them. His models are based on paper wallets and Bitcoin like bitbills, Bitcoin Suisse Crypto Certificates, and BitNotes. Lipkin's smart banknotes also employ QR codes and private keys protected by a tamper-evident device as well as other layers of security and authentication. He does not recommend the use of RFID chips as they could be hacked. These smart banknotes would also be produced by existing security printers, using existing equipment and techniques.<sup>35</sup>

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<sup>33</sup> Ignacio Mas, "Making Digital Money More Like Cash," 16 April 2020, 3-4, ms; Ignacio Mas in discussion with Franklin Noll, 14 October 2020.

<sup>34</sup> Sobotka, *passim*; BitNotes, URL: [www.bitnotes.org/](http://www.bitnotes.org/) (accessed 6 October 2020); "Bitnotes: paper notes backed by bitcoins," *Bitcoin Forum* (11 October 2016), URL: <https://bitcointalk.org/index.php?topic=1643021.0> (accessed 15 October 2020).

<sup>35</sup> Andrei Lipkin, email message to Franklin Noll, 8 October 2020; Andrei Lipkin, *Cryptobanknotes*, URL: <https://photos.google.com/share/AF1QipNxi-tiON2saC5csnh2dQOX12AgrQv98NrMa6Tn8QdA4jQmD-4LDMiVaeINE9eUEA?key=YUUwMERWMGFIWUVRTW5OQWtqeFZBdHJ2ZEIhcUdB> (accessed 15 October 2020).

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The smart banknotes would be denominated and be linked to a unique e-wallet equal in value. Lipkin, as with the BitNotes prototype, believes specialized software will be needed to make the notes operate. This software would act to authenticate the smart banknote and “will simultaneously facilitate the execution of an e-payment of a banknote to any user and cancel the address of an e-wallet” corresponding to the note.<sup>36</sup> Once this happens, the smart banknote is no longer valid. Until this happens, the smart banknote could be passed hand to hand and used as a traditional banknote.

Like Ignacio Mas and Consult Hyperion, Lipkin sees smart banknotes as a transitional device between traditional banknotes and electronic money. Smart banknotes, he argues, will also promote financial inclusion and the use of cryptocurrency. Populations with no or intermittent internet access or electricity will be able to use smart banknotes primarily as traditional currency with the advantage of the notes being denominated in Bitcoin or other cryptocurrency, promoting the new currency in the process.<sup>37</sup>

Mass distribution of a cryptocurrency via smart banknotes, according to Lipkin, would popularize the currency and its use, strengthening its market position and making it more attractive to investors. Wide issuance would also, among other things, reduce cryptocurrency price volatility, increase its market value, and secure it against regulatory claims that the cryptocurrency is a security.<sup>38</sup>

Lipkin promotes the issuance of Bitcoin denominated notes. These smart banknotes would actually be distributed by a central bank which will hold the backing Bitcoin. These notes would be purchased by the populace at a local bank; this bank will also be responsible for remuneration. It is assumed that the notes could be purchased and remunerated in either Bitcoin or the native currency.<sup>39</sup>

### Tangem Note Issuances

Tangem Notes or Cards began development in 2014. The goal of the company was to combine the advantages of cryptocurrency with the ease of usage that came with cash. While using cryptocurrency involved “a steep learning curve” for users, banknotes were well known and simple to use.<sup>40</sup> Everyone knew how to keep banknotes safe. The same could not be said for a cryptocurrency. Much as Ignacio Mas argued, Tangem saw the need to create a device that would operate in the electronic world but with the simplicity and attributes of cash.

From the start, the company, Tangem, worked with a card model similar to bitbills. However, Tangem’s work was independent from that of bitbills. The problem, according

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<sup>36</sup> Andrei Lipkin, email message to Franklin Noll, 8 October 2020.

<sup>37</sup> Andrei Lipkin, email message to Franklin Noll, 29 August 2020.

<sup>38</sup> Andrei Lipkin, email message to Franklin Noll, 8 October 2020.

<sup>39</sup> Andrei Lipkin, email message to Franklin Noll, 8 October 2020.

<sup>40</sup> “Portfolio: These Smart Banknotes Could Bring Crypto to the Masses,” Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020); Kevin Helms, “Bitcoin Smart Banknotes Launched in Singapore,” *Bitcoin.com* (4 May 2018), URL: <https://news.bitcoin.com/bitcoin-smart-banknotes/> (accessed 20 October 2020).

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to Tangem (that perhaps led to bitbills' failure), was that the existing chips “were too slow, lacked elliptic cryptography support, were too insecure, or too power hungry, or prohibitively bulky and expensive.”<sup>41</sup>

In 2018, thanks to advancements in chip and cryptographic technology,<sup>42</sup> Tangem started producing smart banknotes.<sup>43</sup> Tangem Notes were denominated in Bitcoin and Ether and described as:

[S]mart banknotes with a special chip that carries cryptocurrencies or any other digital assets. With these banknotes you can conduct physical crypto transactions just by handing them over or receiving them.<sup>44</sup>

By 2019, Tangem was referring to their product as a card. And, indeed, while denominated, the Tangem smart banknote had and has the look and feel of a payment card rather than a traditional banknote. Tangem argued that such a substrate was necessary to contain the necessary technology and to reduce costs. It also maintained that when production was ramped up to billions of units, the per unit cost of a Tangem Card would rival that of traditional banknotes.<sup>45</sup>

The present Tangem Card operates with the use of Tangem software operating on an NFC-enabled phone. The chip embedded in the card holds the value in cryptocurrency and the private key. Validating the card and the transfer of value off of the card occurs when the Tangem card is held against an NFC-enabled phone running the Tangem software.<sup>46</sup> The private key is generated by and stored within the chip.<sup>47</sup> Tangem Cards are now basically cold wallets that allow any value to be transferred to and from the card, acting as a kind of cryptocurrency gift card.

Tangem has argued that basing the card on cryptocurrency and blockchain added to the security of their smart banknote: “It makes the cost of hacking a single banknote [so]

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<sup>41</sup> “Portfolio: These Smart Banknotes Could Bring Crypto to the Masses,” Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020).

<sup>42</sup> “Portfolio: These Smart Banknotes Could Bring Crypto to the Masses,” Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020).

<sup>43</sup> Kevin Helms, “Bitcoin Smart Banknotes Launched in Singapore,” *Bitcoin.com* (4 May 2018), URL: <https://news.bitcoin.com/bitcoin-smart-banknotes/> (accessed 20 October 2020).

<sup>44</sup> “Portfolio: These Smart Banknotes Could Bring Crypto to the Masses,” Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020).

<sup>45</sup> “Portfolio: These Smart Banknotes Could Bring Crypto to the Masses,” Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020).

<sup>46</sup> “About Tangem Card,” *Tangem*, URL: <https://shop.tangem.com/pages/faq-security-and-technical-details> (accessed 20 October 2020).

<sup>47</sup> “Security & Technical info,” *Tangem*, URL: <https://shop.tangem.com/pages/faq-security-and-technical-details> (accessed 20 October 2020).

uneconomical that it's not worth doing it. Moreover, hacking a single banknote doesn't give you access to other banknotes."<sup>48</sup>

However, this security feature disappears if the card is being used away from an electronic network. Hand to hand, counterfeited cards could pass as genuine cards as there are no visual anticounterfeiting or verification measures on the Tangem Cards. Also, away from an electronic network it is not possible to tell just from visual inspection whether there is any value on the card.

The Tangem Card is reminiscent of the Consult Hyperion idea of a card-type smart banknote. And, it shares the same drawbacks that it would be less socially acceptable to those used to traditional banknotes and it would not be compatible with the existing cash-handling infrastructure. Yet, this smart banknote in card form was adopted by the Republic of the Marshall Islands in January 2019 as a platform for its new national cryptocurrency, existing alongside the US Dollar.<sup>49</sup>

### **Bitcoin Banknote Prototype**

The latest entrant into the smart banknote arena is the firm Independent Currencies. Through its Bitcoin Banknote project, it states a case for the role of cash and traditional banknote printing practices in the world of cryptocurrency. Much like Lipkin, Independent Currencies believes that a smart banknote can act as a transitional device between cash and cryptocurrency while expanding the use of these new currencies.

On the topic of the movement of payments from cash to electronic currencies, Independent Currencies argues that a smart banknote will provide simplicity of use and a degree of anonymity:

Banknotes need no on-boarding, no KYC process, and there are no obstacles [sic] in their use. In contrast, cryptocurrency requires a setup, and an often lengthy and tiresome sign-up process. And in every case, one's identity is tethered to one's transaction history.... There is a coming clash of ideologies, posed by purely digital economies. Keeping cash, and cash-like products circulating may be the pressure release valve that prevents full technological tyranny. The simple fact is that cash

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<sup>48</sup> "Portfolio: These Smart Banknotes Could Bring Crypto to the Masses," Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020).

<sup>49</sup> Stephanie Palmer-Derrien, "The bank of blockchain: Startup to print crypto banknotes for world first digital national currency," *Smart Company* (30 January 2019), URL: [www.smartcompany.com.au/startupsmart/news/bank-blockchain-startup-crypto-banknotes/](http://www.smartcompany.com.au/startupsmart/news/bank-blockchain-startup-crypto-banknotes/) (accessed 6 October 2020); Megax, "Introducing Tangem, The First Smart Banknote for Digital Assets," *Medium* (3 May 2018), URL: [medium.com/megax/introducing-tangem-the-first-smart-banknote-for-digital-assets-1975a209faa1](https://medium.com/megax/introducing-tangem-the-first-smart-banknote-for-digital-assets-1975a209faa1) (accessed 6 October 2020); Kevin Helms, "Bitcoin Smart Banknotes Launched in Singapore," *Bitcoin.com* (4 May 2018), URL: [news.bitcoin.com/bitcoin-smart-banknotes/](http://news.bitcoin.com/bitcoin-smart-banknotes/) (accessed 6 October 2020); Hackernoon, "Portfolio: These Smart Banknotes Could Bring Crypto to the Masses," Solinus (29 January 2018), URL: <https://www.solinus.consulting/portfolio-and-blog/2019/1/11/portfolio-medium-post-2> (accessed 6 October 2020).

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is the most Human, private, and autonomous form of transacting used around the world, with or without cryptocurrency.<sup>50</sup>

Independent Currencies also believes that banknotes instill trust of a currency in the user. This is one role of traditional banknotes and banknote design. Also, banknotes act as a calling card or advertisement for a currency; they establish a brand. Both of these items, trust and recognition, Independent Currencies argues, are needed by cryptocurrencies in order to expand their usage.<sup>51</sup>

Bitcoin Banknote prototypes are based on paper wallets like bitbills, Bitcoin Suisse Crypto Certificates, BitNotes, and Lipkin models. (A card-based Bitcoin Banknote prototype with a chip is also evidently proposed.)<sup>52</sup> How these smart banknotes will function is not explained. Instead, Independent Currencies stresses, like Lipkin, that traditional banknote printing and design are needed to ensure the security of the notes. This is in line with the Bitcoin Suisse Crypto Certificates.

### Smart Banknote Feature Analysis

Breaking down the various models, prototypes, and issuances into major categories, we find six types of features. (The smart banknotes and their features are compared in the table below.) Here is a brief description of the different features:

**Network Access Device.** This is the method used by the smart banknote to communicate with an electronic network. There were basically two devices: chips and QR codes.

**Number of Uses.** The type of Network Access Device used determined the Number of Uses of a smart banknote. Chips allowed for multiple uses of a note as it could be recharged any number of times. Use of a QR code required the destruction of the smart banknote in some way. This made the note a one-use instrument.

**Substrate.** The Substrate is the underlying structure of the smart banknote. Here, the note was either on a traditional banknote substrate—paper or polymer—or a rigid plastic card like present payment cards. Some smart banknote creators have hypothesized that their notes could exist on either platform, specifically Consult Hyperion and Tangem.

**Currency Type.** This is either a traditional fiat currency like the dollar or the euro or a cryptocurrency. Theoretically, smart banknotes using chip technology could handle either form of currency as in the case of Tangem where the chip has the private key, but this function could be turned off for fiat currency. Meanwhile, notes using QR codes are really best suited for cryptocurrencies.

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<sup>50</sup> “The Bitcoin Banknote Project,” *Independent Currencies*, URL: <https://www.bitcoin-banknote.com/> (accessed 20 October 20, 2020).

<sup>51</sup> “The Bitcoin Banknote Project,” *Independent Currencies*, URL: <https://www.bitcoin-banknote.com/> (accessed 20 October 20, 2020).

<sup>52</sup> “The Bitcoin Banknote Project,” *Independent Currencies*, URL: <https://www.bitcoin-banknote.com/> (accessed 20 October 20, 2020).

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**Offline Value Indicator.** This is a feature that allows the user to determine whether a smart banknote contains its denominated value when not connected to an electronic network. The two early models use an E Ink display. Most cryptocurrency notes use only a tamper evident feature, usually foil over the QR code for the private key. Tangem has no indicator that can be used offline to indicate whether its card contains any value.

**Offline Authenticating Feature.** This is a feature or a set of features that allows the user to determine whether a smart banknote is authentic or a counterfeit. Foils and even chips can be counterfeited. Strong Offline Authenticating Features are those currently used in traditional banknotes like optically variable inks, complex intaglio printing, UV ink tags, 3D ribbons, and the like. These features require a paper or polymer substrate. Cards are limited in their ability to hold these features if only because of their smaller surface area when compared with traditional banknotes. And, the cards reviewed here do not hold Offline Authenticating Features.

Model, Prototype, Issue	Network Access Device	Number of Uses	Substrate	Currency Type	Offline Value Indicator	Offline Authenticating Feature
Ignacio Mas	Chip	Multi	Paper / Polymer	Fiat	E Ink	Traditional Banknote
Consult Hyperion	Chip	Multi	Polymer / Rigid Card	Fiat	E Ink	Traditional Banknote
bitbill	QR code	Single	Rigid Card	Crypto	Tamper Evident Feature	None
Bitcoin Suisse	QR code	Single	Paper / Polymer	Crypto	Tamper Evident Feature	Traditional Banknote
BitNotes	QR code	Single	Paper / Polymer	Crypto	Tamper Evident Feature	None
Andrei Lipkin	QR code	Single	Paper / Polymer	Crypto	Tamper Evident Feature	Traditional Banknote
Tangem	Chip	Multi	Rigid Card	Crypto / Fiat	None	None
Bitcoin Banknote	?	?	Paper / Polymer / Card	Crypto / Fiat	?	Traditional Banknote

### Critical Smart Banknote Features

What features are critical or fundamental for a smart banknote? Remember, the definition of a smart banknote is that it is a physical banknote on a paper or polymer substrate that can communicate with an electronic network. A smart banknote is denominated and has the physical properties of a traditional banknote in size, feel, appearance, and etc.

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The purpose of a smart banknote is to function offline for all intents and purposes like a traditional banknote. However, it has the added ability to communicate with an electronic network. So, reviewing this mission and the features laid out above, a smart banknote needs the following features:

**Network Access Device.** A smart banknote will require chip technology. This will allow for the note to hold value for either a fiat or crypto currency. A chip is also necessary to provide for multiple uses of a smart banknote.

**Number of Uses.** A smart banknote needs to be able to be connected to an electronic network repeatedly, transferring value to and from the note. This is necessary to replicate the experience of using a traditional banknote more closely and to lower the cost of smart banknote issuance.

**Substrate.** For a smart banknote to approach the physical properties of a traditional note, it needs to be on the same substrate—paper or polymer. Cards are foreign to the banknote experience.

**Currency Type.** A smart banknote can function with either a fiat currency or a cryptocurrency as long as the chip technology allows it, as it appears in the case of Tangem. In this case, a central bank could issue a smart banknote that is actually a central bank digital currency instead of its fiat currency. Also, a private cryptocurrency company or foundation could issue its own smart banknotes denominated in its currency.

**Offline Value Indicator.** Given the need for multiple uses and for offline verification that a note still maintains its value, E Ink or some other technology is needed that is powered by the note's chip.

**Offline Authenticating Feature.** A smart banknote requires all the security features of a traditional banknote as it cannot depend upon a user's ability to connect it to an electronic network to verify its authenticity.

So, in sum, a smart banknote suitable for use with a fiat or crypto currency must use chip technology embedded in a paper or polymer substrate (both able to provide multiple uses) and have on its surface features that allow a user to determine its value and authenticity when the note is not connected to an electronic network.

### **Smart Banknote Production Challenges**

There are a great many issues to be dealt with regarding the smart banknote life cycle and functionality before such a device as outline above becomes fully implementable from its printing, to its electronic network, to its acceptance in vending machines, to its destruction, and so on. However, for the purposes of this paper, we will only address the challenges of the critical features needed in a smart banknote. And, here, briefly, we will look at the three major challenges facing the creation of a physical device.

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### 1. How does one embed a chip in a paper or polymer substrate?

If we accept that smart banknotes will be produced largely with existing security printing equipment and that the chip can be based on the existing technology, the major question is how to create a smart banknote that can hold a chip?

The major problem is that the chip cannot be embedded in the substrate at the manufacturing plant. This is not because the paper or polymer manufacturer lacks the ability to do this. It is because one cannot run a sheet of banknote substrate bearing a chip through an intaglio press, which can produce 60 tons of pressure. The chip would be destroyed.

A chip will need to be introduced into the note after the intaglio printing has been applied. One way to do this is to sandwich it between two layers of paper or polymer after intaglio printing. Sandwiching features between two sheets has been done from time to time since the nineteenth century. However, the process is more expensive and there is always the problem of the sheets separating during use. Yet, it is within the realm of possibility. Technology may also exist for printing a chip or its equivalent onto a banknote.

Printing a banknote with a chip will also produce many challenges downstream from the intaglio press such as sheet stacking, overprinting, and packaging. But, these are problems to be discussed elsewhere.

### 2. How will value be communicated offline, including to the visually impaired?

The use of E Inks, first proposed in 2010 and discussed in this paper, appear the most feasible way to indicate that a smart banknote holds value when it is away from an electronic network. The E Ink would be set to the appropriate display when it is put online.

However, how would the blind and visually impaired be able to determine the viability of a smart banknote? A tactile feature of some sort would be required. One way to handle this problem is again through E Ink. E Ink could form different patterns or depths to indicate whether a note held value or not.

### 3. How will authenticity be communicated offline, including to the visually impaired?

This challenge is the easiest to meet as it is already being met through existing banknote design and security features. Optically variable inks, complex intaglio printing, UV ink tags, 3D ribbons, and tactile features for the visually impaired are already being implemented. The challenge facing banknote designers will be to integrate chip and E Ink features into the small amount of real estate on a banknote.

## Conclusion

Since their inception in 2010, smart banknotes have taken many forms but shared many characteristics. These commonalities stem from the notes having the same overall mission, to create a device that brings together the world of cash and traditional banknotes and the world of cryptocurrencies and electronic networks.



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The work on smart banknotes over the past ten years results in an item that can be used for fiat or crypto currency and that must use chip technology embedded in a paper or polymer substrate (both able to provide multiple uses) and have on its surface features that allow a user to determine its value and authenticity when the note is not connected to an electronic network.

Creating such a smart banknote and issuing it in large quantities will face many technical challenges, especially embedding a chip in a banknote substrate and using E Ink or other technology to indicate the note's value offline. However, these technologies are within reach. And, the offline authentication is already being accomplished on current traditional banknotes.

Transcending the division between the world of banknotes and electronic money through a smart banknote will bring many advantages to central banks and cryptocurrency advocates. This paper has presented the basic functional framework for such a device, however, as always, the devil is in the details.

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